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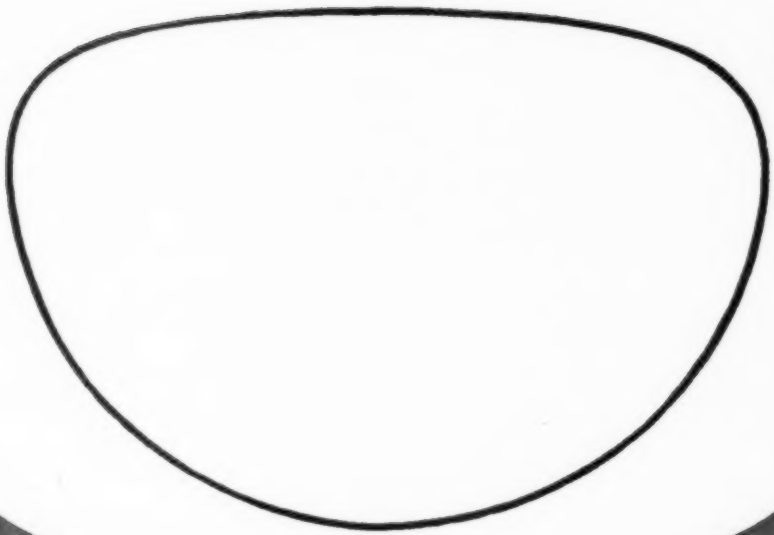

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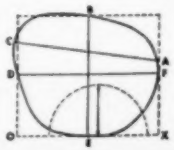

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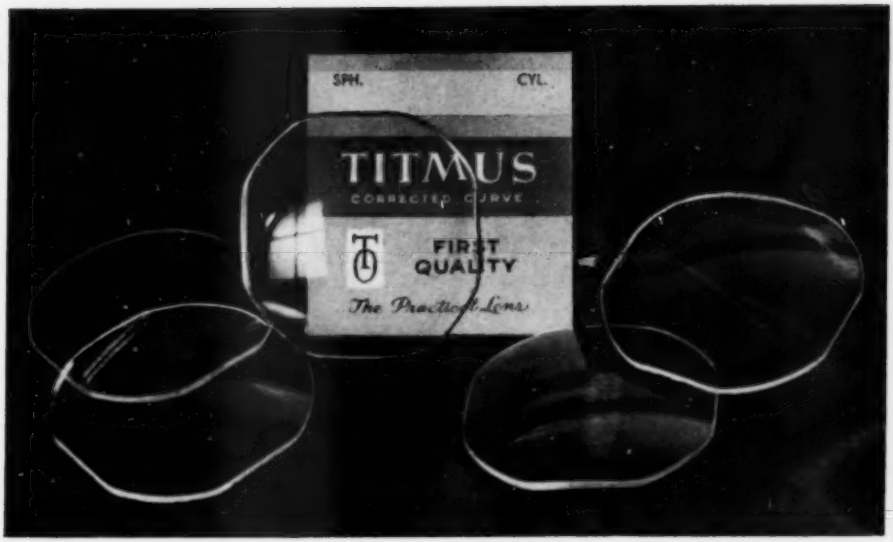

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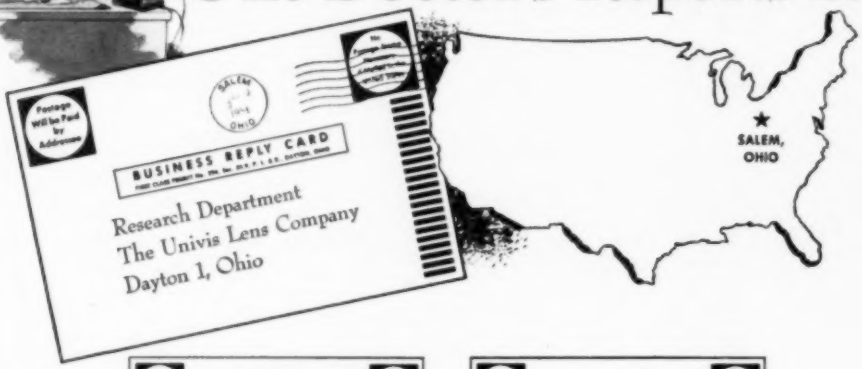

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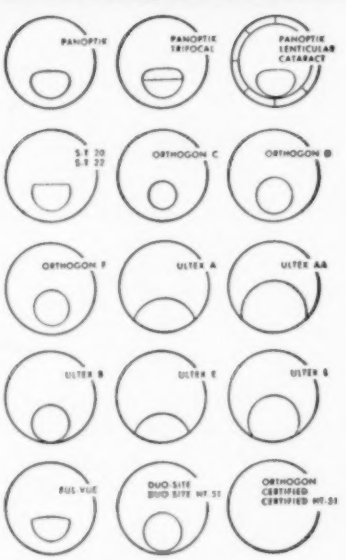

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MEASURING TONIC CONVERGENCE*

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Some 60 years ago Maddox[7] proposed that the function of convergence is composed of four parts: tonic convergence, accommodative convergence, fusional convergence, and psychic-nearness convergence. It is possible to define each component with reasonable clarity and simplicity, excepting perhaps the tonic convergence component, and all except tonic convergence may be more or less readily measured. Measurements have been cited for tonic convergence. However, since various authors have used the term *tonic convergence* to refer to components of convergence which differ in many respects, the measurements cited have not necessarily been measurements of the sort of tonic convergence which Maddox had in mind.

The differences may have arisen because there are inconsistencies in the ways which the words *tone*, *tonic* and *tonus* are used in general physiology. Each of the somewhat different definitions of tonus may then be applied to convergence, and there then result as many different kinds of tonic convergence. It is also possible that some of those who independently used the term *tonic convergence* and gave it a somewhat different meaning may not have known of the ideas of Maddox.

Until recently, it could be said that there were essentially three different definitions of tonus. New research may now require the addition of a fourth definition.

One of the older definitions is illustrated in the writings of Carlson and Johnson.[2] who regard tonus as the low degree of continuous activity which exists in muscles or nerves when they are at "rest."

Even if this were the only viewpoint toward the meaning of tonus,

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the differences among those who disagree about the meaning of ocular tonus and tonic convergence could be credited to differences in interpreting the word *rest*. One could, with some justification, state that the position of rest is the one which the eyes assume during sleep. One could reasonably regard the dissociated position with fixation at a six-meter or greater distance and no stimulus to accommodation present as the position of rest. There might possibly be some reason for assuming that the position of rest is attained while the eyes are bifixating a distant object so that the visual axes are parallel.

Regardless of differences in attitude toward tonic convergence, the classification of convergence by Maddox into components has been found to be in general agreement with present-day knowledge concerning convergence.

If the viewpoint of Maddox toward tonic convergence can be said to agree with any of the definitions of tonus, the agreement is with the first definition, the one which considers tonus as the activity which exists in muscles during "rest." The "rest" referred to is, of course, not an absolute rest, that condition which would result if there were absolutely no activity at all in the muscles of the eyes, a condition which would, according to general opinion, be attained only when the muscles are totally denervated or after death.

Discussing tonic convergence, Maddox wrote:

> We must first ask "What is the *starting point* of convergence?" We do not exactly know what position the eyes would take in the absence of any converging innervation, though the divergence which follows in monocular amblyopia seems to shew it be one of considerable divergence. Were all the innervations to cease, the anatomical position of rest of the eyes would undoubtedly be one of considerable divergence. . . . The ocular muscles no doubt possess a physiological tone, similar to that of the other skeletal muscles, but what influence it has on the eyes is difficult to decide. . . . By this tonic convergence, the visual axes are brought to practical parallelism, so that on viewing a distant object, and occluding one eye, it either remains undeviated, or only aberrates slightly, more often in the direction of divergence than convergence in emmetropia. . . .

He then explained that during waking hours the eyes are brought by tonic convergence from their position in anatomical rest to the position

> . . . that is noticed when we use V. Graefe's "distant equilibrium test," or any of its successors, such as the double prism or glass rod. Latent divergence in distant vision indicates a deficiency, a latent convergence an excess, of *tonic convergence*. In either case the aberration is corrected, when both eyes are in use by reflex convergence, positive or negative, as the case may be.

Latent divergence, of course, is now commonly called exophoria; latent convergence is esophoria.

The position of rest during which only tonic convergence would act is the position which has come to be known as the position of physiological rest of the eyes.

Since the fixation target used during a heterophoria measurement

is usually at least six-meters distant, the possibility is eliminated for convergence to be stimulated because of any psychic-nearness factor. During the distant equilibrium or heterophoria test, fusional convergence is for practical purposes eliminated. While the test is made, any observer with a refractive error should be fully corrected so that no accommodation is stimulated, and consequently accommodative convergence is eliminated. As a result, tonic convergence can be considered as that part of convergence which remains after eliminating all the other Maddox components. In this sense it is a left-over and can be due to the summated activity of a number of factors.

According to Maddox, only tonic convergence is acting when the eyes are in the fusion-free or dissociated position with fixation at distance, the position corresponding to that held by the eyes while the heterophoria is measured clinically with fixation upon a six-meter-distant target. The heterophoria measurement is usually recorded in terms of the amount of exophoria or esophoria or, if no deviation from the primary position exists, as orthophoria. Though Maddox did not do so, it is not uncommon to represent exophoria as negative tonic convergence, esophoria as positive tonic convergence, and orthophoria as zero tonic convergence.[8] Thus, 3Δ esophoria is recorded as +3Δ of tonic convergence. When this practice is followed, it is rather easy for others to draw the inference that tonic convergence represents the deviation of the eyes from the primary position to the fusion-free position. Some writers are careful, however, to specify that this means that tonic convergence *fails* by 3Δ in bringing the visual axes to the fixation position, and that for bifixation to ensue, the visual axes must be brought to the proper position by fusional convergence which is equal to the tonic convergence but opposite in sign. In this case, —3Δ of fusional convergence would be required; i.e., a relative divergence movement of the visual axes would occur. Part of what is often termed the capacity for abduction or, more correctly, the negative vergence capacity would then be used. From this there results the improper generalization that when a subject fixates a distant target, the fusional convergence activated is equal to the tonic convergence but opposite in sign. This latter comparison was, however, never made by Maddox. It would be true only if the position of anatomic rest were to coincide with the primary position of the eyes.

Scobee's writings illustrate a different use of the word *tonic*. According to Scobee:[9]

> *Fixation* means the maintenance of posture of the eyes by tonic contractions of the oculorotary muscles so that the retinal images fall on the fovea.

In a way it would be correct to say that if the muscle contractions

are tonic, the convergence is tonic. Scobee also defines tonus:

> When the eye is fixating, nervous impulses are constantly sent down the nerves, resulting in a contraction of the antagonistically acting muscles; this contraction is known as *tonus*.

In other words, whenever the eyes maintain a constant position, regardless of how much convergence is acting, the contraction is tonus.

This is not inconsistent with the use of the word *tonus*. The physiologist Bard[4] has written:

> Perhaps the most outstanding feature of smooth muscle is its peculiar tendency to exhibit a sustained persistent contraction known as *tonus*.

The extraocular muscles, it may be added, are not regarded as smooth muscle, though they react to certain drugs as if they were smooth muscle. Bard explains:

> The nouns "tonus" and "tone" and the adjective "tonic" are used in physiology to signify processes that are, in certain respects, quite dissimilar. Aside from the tonus of smooth muscle we speak of: vagal tone and vasoconstrictor tone each of which denotes a constant, hence "tonic," discharge in specific nerve fibers; the tonus of skeletal muscle which, as we shall see, is due to a fusion of asynchronous incomplete tetani in the fibers of different motor units; and even cardiac tonus which has a less precise meaning and which usually refers to the general condition of the heart. Used unqualifiedly the word "tone" signifies a persistent, rather moderate degree of activity.

A second definition of tonus, then, is that it constitutes a sustained, persistent contraction.

Duke-Elder[5] appears to support a viewpoint that differs significantly from that of Maddox. He classifies convergence into two types, involuntary and voluntary. Referring to involuntary convergence, he writes:

> The total excursion from the position of rest is therefore usually spoken of as consisting of three components—*tonic convergence, accommodative convergence* and *fusional convergence*.

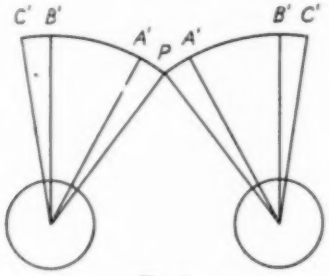

Fig. 1.

In a diagram similar to Figure 1, he shows that PC' is the total convergence, of which C'B' is the tonic convergence, B'A' the accommodative convergence, and A'P the fusional convergence. The near-point of convergence is at P, at C' the eyes are in the position of rest, and at B'

they are directed straight forward. It would seem that he believes that tonic convergence is a form of fusional convergence used for a special purpose when he writes:

> In normal circumstances it is a fusional movement that is constantly being employed, for in so far as the usual position of rest is one of slight divergence, a moiety of convergence is required to maintain parallelism of the eyes in the primary position *(tonic convergence)*.

It is not quite clear from this statement alone what he means precisely by the position of rest. Elsewhere in the same volume he carefully defines the functional binocular position, the fusion-free or dissociated position, the physiological position of rest, and the anatomical (absolute) position of rest. He writes that while in the dissociated position the eyes are "at ease." The physiological position of rest is attained in such states as deep sleep or anesthesia, and the anatomical position is realized in complete external ophthalmoplegia.

If tonic convergence is a fusional movement that is constantly being employed to bring the eyes to the primary position from "the position of rest," then the position of rest referred to must be the dissociated position of the eyes. That this is actually what is meant is confirmed by what Duke-Elder[4] writes concerning heterophorias.

> In the presence of any of these errors the desire for fusion, excited reflexly by the presence of double vision, brings about a movement of the eye designed to correct this imbalance, and maintains the eye in this position and if the stimulus for fusion is abolished by covering up one eye, or by dissociating the images of the two so that they cannot be merged in a single perception in consciousness (as by distorting the image of one by a Maddox rod), the converse movement into a position of rest occurs.

It is generally stated that the anatomical position of rest is one of divergence of about 10°, but Cogan[3] states that the eyes are directed straight ahead or only slightly divergent in death. So it might conceivably be possible that point C' represents instead the position of anatomical rest, or even of physiological rest. But it is known that during consciousness the tonus of the eye muscles does not itself usually bring the eyes to a position of parallelism of the visual axes; some fusional movement must almost always assist. Neither is the entire movement of the eyes from the anatomical position of rest to the bifixation position usually described as a fusion movement. Part of the movement may be due to extraocular tonus; the remaining movement has to be due to fusional convergence.

From this, it appears that Duke-Elder in considering tonic convergence adheres to the second definition of tonus.

If Duke-Elder's procedure were followed, a person with 4Δ of exophoria would use 4Δ of tonic convergence to bring the eyes to the primary position. The tonic convergence for such a person would be +4Δ. In a way this is in contrast to the previously mentioned pro-

cedure by which it would be said that —4Δ of tonic convergence exists, and that to bring the eyes to the primary position, +4Δ of fusional convergence would be used.

Cogan, like Duke-Elder, believes that fusional convergence can be tonic convergence. He writes:

> The retinal images are disparate when the images of an object do not fall on the corresponding points in the two eyes. Muscle tonus is concerned primarily with the disparateness arising from the maculas; only when there is no cause for disparateness in the center of one's field, will disparateness in the peripheral areas be an important factor.

It is commonly held that fusional convergence is the process by which the eyes react to retinal disparity so that bifixation may result.

Cogan's views are, however, significantly different from those of Duke-Elder. Duke-Elder would apparently include in tonic convergence only such fusional convergence as is required to bring the eyes to parallelism. Cogan includes all fusional convergence as ocular tonus, and in addition he also includes other factors as contributors to ocular tonus. It would appear that he believes that all these factors, fusion included, are responsible for bringing the eyes from the position of anatomic rest to the bifixation position. If this is so, then this entire movement could be considered as the amplitude of tonic convergence.

Since Cogan makes no reference to maintenance of the position of the eyes by this sort of convergence, but implies that any disjunctive movement of the eyes is of a tonic origin, it cannot be said that he completely adheres to the second or any other definition of tonus.

Proper adherence to the convergence components suggested by Maddox would, of course, dictate including under fusional convergence all types of fusional convergence, even that amount which is constantly active during bifixation. No fusional convergence would contribute to tonic convergence.

Concerning tonus, Wiggers[10] has written:

> This is a sustained state of partial contraction exhibited to varying degrees by muscles in the body, and is characterized by abolition after motor nerve section.

Wiggers then makes an important distinction.

> Physiologically, tonus is a part of the reflex mechanism concerned in postural adjustments, hence the term "postural contraction" is more descriptive. As phrased by Sherrington, "Reflex tonus is, in short, reflex posture—a reflex which differs from reflexes more commonly studied in this, that the latter execute *movements* while this maintains posture."

So, a third definition of tonus is that it is a reflex, postural contraction.

The usually accepted viewpoint is that body tonus is mainly associated with the antigravity muscles, those muscles which are responsible for maintaining the standing position. Since the time of Sherrington, it has been claimed that an exaggeration of this activity is seen in the

decerebrate rigidity of animals. The contractions of the eye muscles, of course, do not help an animal to stand, but if any of the eye movements are postural, it is those which are designed to keep the eyes in a constant relationship to fixated objects no matter what head or body movements occur. The compensatory eye movements which accompany head movements when one moves his head from side to side as if to indicate no, or up and down as if to indicate yes, are examples. The tendency for the vertical meridians of the eyes to remain vertical even when the head is inclined toward a shoulder is another such case. In the latter instance compensation in man is not complete. This type of reaction, controlled by labyrinthine and neck proprioception, can be considered as being of a more primitive nature. Superimposed upon this mechanism is the ability of the eyes to converge and to undertake pursuit movements in order to follow moving objects. Neither pursuit movements nor the convergence of the eyes for near-approaching objects can easily be considered as postural reactions.

Mechanically, any disjunctive movement of the eyes in the plane of regard is positive or negative convergence. Tonic convergence appears in certain ways to be partly a manifestation of the postural reactions of the eyes which only indirectly bring about mechanical convergence. Tonic convergence is also a left-over, and it must as well be composed of certain factors which are not exactly postural. Tonic convergence may be thought of as preparing the motor-nervous system and muscles of the eyes so that when the demands of binocular vision are placed upon them, they may respond satisfactorily. If tonic convergence does not adequately prepare the eyes, as is the case in certain types of strabismus, the other three components of convergence cannot then carry out their designated task of providing effective bifixation.

Accepting tonic convergence as the movement of the eyes from their position in anatomical rest to that of the dissociated position at distance, we must admit that the factors which contribute to tonic convergence are not yet too well understood. A number of factors are usually spoken of as contributing to extraocular tonus, but these factors are as a whole only indirect contributors to convergence. A detailed consideration of these factors is the subject for a subsequent paper.

In terms of physiological realities, it would be better to add points D to the convergence diagram, letting D indicate the position of anatomical rest. Then true tonic convergence would be represented by arcs DC' (Figure 2). This is a measurable function, but it is not at all easily measured, and for clinical purposes it cannot be measured, since it depends on knowing the position of anatomical rest. The fact that

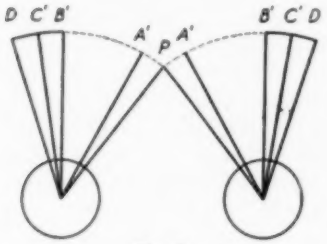

Fig. 2.

true tonic convergence cannot clinically be measured does not justify calling an easily measurable function tonic convergence. What is commonly measured as tonic convergence is actually what might be called a tonic convergence disparity. This is recognized by those who give a value of —4Δ tonic convergence to a person with 4Δ exophoria and who also qualify this by stating that this means that tonic convergence fails by 4Δ to align the visual axes for bifixation at distance.

Designating true tonic convergence as that amount of convergence which brings the eyes from the position of absolute rest to the dissociated position at distance does not violate physiological principles and is in agreement with the concepts of Maddox.

It is unnecessary to introduce the term *tonic convergence disparity* for what is already known by the terms of *heterophoria* or *heterotropia*. But it should always be understood that such deviations of the eyes are actually disparities or failures of tonic convergence to bring the eyes to the primary position. Even though the value of such a disparity is known, the value of true tonic convergence would be known only if the absolute position of rest were also known

By definition, the position which the eyes assume as a result of tonic convergence must be determined with distance fixation. Figure 2 fulfills this condition: B'C' represents the heterophoria, DC' represents the tonic convergence, and C'B' represents the fusional convergence in use during distance bifixation.

In terms of the Maddox components, Figure 2 is still incomplete. The object P is at the near-point of convergence, and yet there is no representation of psychic convergence due to nearness. For the dissociated position at near fixation, represented on Figure 3 at E, any added convergence above that present for the dissociated position for distance fixation and not contributed by accommodative convergence is defined as psychic-nearness convergence, and is shown by arcs A'E.

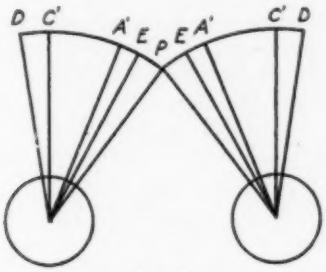

Fig. 3

The position of anatomic rest is at D, while C' represents the dissociated position for distance fixation. The tonic convergence is shown by arcs DC'; arcs C'A' represent the accommodative convergence; arcs EP designate the fusional convergence in use to bifixate point P. By definition, Figure 3 is complete, but it is not necessarily functionally realistic.

One can divide total convergence into parts, but it is difficult to assert positively that the neurological basis for the arbitrary components is not affected by changes in the total level of activity of the function of convergence. By definition, tonic convergence is the same for all fixation distances, but this does not in itself eliminate the possibility that there may be some functional relationship, for example, between tonic convergence and psychic-nearness convergence. Such inter-relationships were even suggested by Maddox himself, who thought that tonic convergence and psychic-nearness convergence were "perhaps closely related."

More recently, Morgan[5] made a statistical study which tends to indicate

> that psychic nearness convergence is a learned function much like a conditioned reflex and that it is a special manifestation of fusional convergence and not a separate innate reflex or a part of accommodative-convergence as assumed by Maddox.*

Hofstetter,[6] after investigating convergence relationships, interpreted his findings as indicating that although

> proximal convergence is closely associated with the amount of fusional convergence in play . . .. proximal convergence and fusional convergence have independent neurological origins.

SUMMARY

Conflicting definitions of tonic convergence are discussed. That

*The words of Maddox are: "Of these four elements I have included the second and third [accommodative convergence and psychic-nearness convergence] under the name of 'accommodative convergence' to simplify practical work."

of Maddox is held to be the most acceptable. Diagrams indicating the relationship of tonic convergence to total convergence are presented. The types of measurements which are cited as measurements for tonic convergence are mentioned, and it is concluded that true tonic convergence cannot be measured clinically.

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ABSTRACTS

NEEDLESS REFERRALS. Richard G. Scobee. Editorial. Am. J. Ophth., 33 (8), 1302-1303, August, 1950.

This is an excellent discussion of the handling of school children referred by their teachers for eye examinations. Of particular importance is the manner in which the eye specialist tells the parents there is nothing wrong with the child's eyes. If a gruff, abrupt manner is used, the parents are apt to condemn the school nurse or teacher and frequently the eye specialist as well, for charging a fee when nothing was found wrong.

In cases where nothing is found, Scobee suggests informing the parents that they are fortunate that the examination revealed nothing seriously wrong with the child's eyes and that whatever made the school nurse or teacher suspicious must have been a temporary condition. Secondly, the parents should be impressed that they are fortunate their child attends school where attention is given to more than books. This type of reasoning with the parents usually results in a feeling of confidence and pride in the school system, their child, and the doctor.

The schools with their limited facilities do the best they can to detect visual defects and call them to parents' attention. However, such programs result in a certain number of needless referrals. The manner in which these needless referrals are handled can make a big difference in the relationships between family and school.

ROBERT E. BANNON.

THE BIOPHYSICS OF CORNEAL SCATTER AND DIFFRACTION OF LIGHT INDUCED BY CONTACT LENSES*

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PART II

D. Determination of Diffracting Particle Size from Halo Diameters

If the diameter of these particles is denoted by d we have:

$$d = \frac{k_1 \lambda}{\sin B_1} \qquad (3)$$

where $k_1 = 1.648$‡

$\lambda = 0.546$ microns (wave length of the mercury green line)

B_1 = the angular radius of the halo as measured empirically.

For the third maximum the value of K_2 is 2.666 and the equation becomes:

$$d = \frac{k_2 \lambda}{\sin B_2} \qquad (4)$$

where B_2 is the angular radius of the second ring.

After some time, such a second halo becomes visible when wearing a contact lens. Its appearance provides an opportunity for testing whether it is really a member of a single diffraction system, and therefore caused by particles of a single size, or whether a double or possibly different diffraction system is involved.

By equating the right hand members of equations (3) and (4) we obtain:

$$\sin B_2 = \frac{k_2}{k_1} \sin B_1 \qquad (5)$$

from which the angular radius of the second or, in a similar fashion, of any other halo of the system can be computed. If the angular radius

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Submitted to the faculty in partial fulfillment of the requirements for the degree of Doctor of Philosophy, in the Faculty of Pure Science, Columbia University, New York City.

Part I of this paper appeared in the April, 1952, issue.

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‡This is the value assigned to k, by Lommel for the second maximum of a system of circular diffraction haloes produced by circular apertures or spherical particles in Fraunhofer diffraction.[30]

so computed does not differ significantly from the observed value, then the probability is that particles of a single size are responsible. If a significant difference does appear, then particles of at least two different sizes may be involved. The presence of some other form of diffraction system or displacement due to optical aberrations of the eye may be alternative explanations.

1. *Apparatus*

A tangent scale is mounted close to and parallel with the front face of the halometer. Its zero coincides with the center of the primary source and extends to 8° outward in steps of one-tenth of a degree, subtended at the observation point. Traveling along this scale is a narrow slit illuminated by a small neon bulb.

2. *Procedure*

This dimly illuminated slit was moved slowly along the scale until the subject reported that it occupied the center of the halo. The radius of the halo was then read directly on the scale. The mean of four readings constituted a single determination.

3. *Results*

Table VI gives the measurements for one of our subjects. Those for the remaining two are entirely comparable and are, therefore, not shown. The diameters of both haloes are practically constant for a single observer for a wide variety of solutions, and throughout the course of halo development for any single solution. The only change, therefore, is in brightness. Moreover, the halo size differs little from one observer to the next.

The mean angular radii of the first haloes, and that of the observed and computed second haloes, for all three of our subjects, are given in Table VII. The critical ratio $\frac{D}{P.E._D}$ for testing the probability that the computed value is significantly different from the observed value is also given, where D is the difference between these values and $P.E._D$ is the probable error of the difference computed from the average deviation of each mean. The respective probabilities that the difference is other than zero are tabulated, as are the particle sizes independently computed from the observed radii of the first and second haloes respectively, on the assumption that the diffraction is particulate and that the second halo is the third maximum in an ideal diffraction system corresponding to a single particle size. The reliability of the evidence derived from a single subject is decidedly greater when such close agreement between all three subjects is obtained, as the table indicates.

TABLE VI

Angular Radius of the First and Second Haloes as Observed by Subject B. D.

Date	Solution Used	Elapsed Time*	Optical** Condition	Mean Angular Radius of Haloes*** Primary (B_1)	Secondary (B_2)
8:9:50	$NaHCO_3$ ⅜ %	15 minutes after removal: after 6 hrs. 57 min. wear	s	3.02 ± 0.05: 4	6.09 ± 0.09: 4
8:23:50	$NaHCO_3$ ¼ %	1 hr. 32 min.	c	3.17 ± 0.06: 5	6.13 ± 0.08: 4
10:4:50	$NaHCO_3$ 1½ % with fluorescein ⅛ %	4 hrs. 36 min.	c	3.24 ± 0.03: 4	6.27 ± 0.08: 4
		6 hrs. 33 min.	c	3.22 ± 0.08: 4	6.33 ± 0.11: 4
10:25:50	$NaHCO_3$ 1½ %	5 hrs. 11 min.	c	3.03 ± 0.05: 4	5.89 ± 0.13: 4
11:6:50	Phosphate buffer 'Obrig B'	6 hrs. 12 min.	s	3.42 ± 0.06: 4	
Mean for the entire distribution				3.183	6.144
Average deviation of the mean				± 0.03	± 0.04

*Since insertion of contact lenses. **c = with contact lenses; s = without contact lenses. ***A single entry is of the form a ± b: n. where a = Mean size. b = Average deviation of a single observation. n = Number of observations.

TABLE VII

Particle Diameters, and Observed and Computed Halo Sizes.

Subject	First Halo (Observed) Angular Radius in Degrees	Second Halo (Observed) Angular Radius in Degrees	Second Halo (Computed) Angular Radius in Degrees	Critical* Ratio D/P.E.D	Probability of a Significant Difference
B. D.	3.18 ± 0.03	6.14 ± 0.04	5.19 ± 0.03	4.0	99.7%
J. E.	3.19 ± 0.01	6.14 ± 0.04	5.20 ± 0.02	3.8	99.0%
H. K.	3.15 ± 0.02	6.14 ± 0.06	5.13 ± 0.04	3.9	99.6%
Subject	Particle Diameter from First Halo (Observed) in Microns	Particle Diameter from Second Halo (Observed) in Microns			
B. D.	16.1 ± 0.2	13.6 ± 0.08			
J. E.	16.1 ± 0.05	13.6 ± 0.08			
H. K.	16.2 ± 0.1	13.6 ± 0.10			

*Where P.E.D = the probable error of the observed difference as computed from the average deviations (a.d.)$_1$ and (a.d.)$_2$ of the observed and computed second haloes respectively, as follows:

$$P.E._D = .845 \sqrt{(a.d.)_1^2 + (a.d.)_2^2}$$

and D = the difference between the angular radii of the tabulated observed and computed haloes.

4. *Conclusions*

For each of our three subjects, the angular radius of the observed second halo was significantly larger than that computed by equation (5). On the assumption that the diffraction is of the particulate variety, two sets of particles would appear to be involved. Histologically, this need not be surprising, for a change of refractive index of the cytoplasm of a cell, its nucleus, and the interstitial fluid, could easily produce such an effect. Alternatively, two different sets of cells of different size may be involved, and this condition is also histologically possible in the cornea. In either case the observed second lateral halo would then be the first lateral halo in a separate diffraction system, corresponding to a particle diameter of about 8.4 microns. In addition to particulate diffraction, a form of laminary diffraction[31] characteristic of mixed plates also is possible. The endothelium is a likely seat for such a diffracting system for, since it is a one-cell thick sheet, if the indices of the cytoplasm and nuclei become sensibly different, each would impress a different phase retardation on light passing through which could result in a set of haloes such as those observed. Possibly this problem could be solved by phase microscopy more readily than by conventional histological or histochemical techniques. The additional possibility that optical aberrations may play a part exists. The angles of diffraction corresponding to the second and third maxima may, and probably do, differ in an actual system from that required in an ideal system for a path difference of $\frac{3\lambda}{2}$ and $\frac{5\lambda}{2}$ respectively, where λ is the wave length of light.

E. *Estimate of Particle Size and Distribution by Biomicroscopy*

1. *Apparatus*

Slit lamp and corneal microscope.

2. *Procedure*

The subject wore a contact lens until a distinct halo developed. The lens was removed and the cornea examined with a slit lamp, magnification 40X. The slit lamp beam was incident at a wide angle from the nasal side and was directed at the temporal margin of the pupil. The corneal microscope was directed at a wide angle from the temporal side toward the area lying between the bright corneal prism and the illuminated pupil margin seen dimly because it was out of focus.

3. *Results*

Figure XVIII shows a uniform cloud of faintly luminous spots. These are not easily localized or measured, nor is it easy to establish

Figure XVIII
Peppering Effect as Observed by Slit Lamp Study.

whether they are material particles or merely small specular reflections from corneal elements whose refractive indices have changed. They were seen in all our subjects.

4. *Conclusions*

If these are material particles they seem too small to cause the observed haloes. They seem to be of the order of 5μ in diameter. If they are reflections they may well be related to the diffracting elements. If these spots are related to effective particles, then their uniform distribution is objectively confirmed. Further study is required to establish their nature.

F. *Differential Scatter as Determined by the Anomaloscope. Estimate of the Size of the Scattering Bodies.*

For particles sufficiently small, as compared with a wave length of light, scatter is inversely proportional to the fourth power of the wave length.[32] If a beam of heterogeneous light passes through a scattering medium in which the scattering particles are sufficiently small, the high frequency components will be more completely scattered than the low frequency components, and they will therefore predominate in the transmitted light.

1. *Apparatus*

We applied this principle by using the Bausch and Lomb model of the Rand Anomaloscope.* The instrument consists essentially of a divided photometric field, one-half of which is illuminated with monochromatic yellow light whose brightness can be varied. The other half is illuminated with a mixture of monochromatic red and green light whose resultant is an intermediate yellow that can be shifted

*This instrument was graciously loaned to us by Dr. Gertrude Rand of the Knapp Memorial Laboratory of Physiological Optics.

toward the red or green by introducing more or less of one of the components. A reading consists of matching both halves of the field for hue and brightness. The relative values of red and green light are indicated on an arbitrary scale whose readings increase with the green component of the mixture.

2. *Procedure*

The scatter kinetics were determined for 0.125% $NaHCO_3$ and 1.5% $NaHCO_3$ for all our subjects. A zero reading of the anomaloscope was obtained as soon as the lens was inserted. Matches were made at 15 minute intervals, thereafter, for the 0.125% and at half hour intervals for the 1.5% solutions.

3. *Results*

Figure XIX indicates the results. The curves shown represent two runs for each of our three subjects obtained by the method of

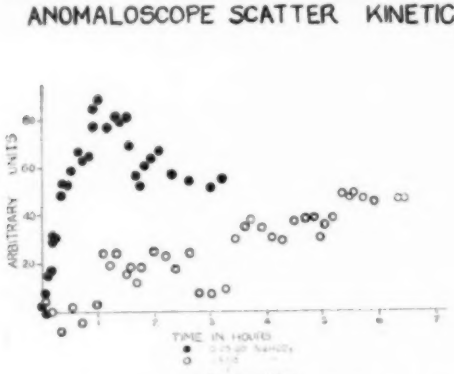

Figure XIX
Scatter Kinetics as Shown by the Anomaloscope. Composite Curve for Three Subjects.

running averages. The maximum in the 0.125% curve is a statistical artifact and is not present in the individual curves.

4. *Conclusions*

Differential scattering occurs when contact lenses are worn. The kinetics of this scatter closely follows that determined with the photometer and indicates that the bodies responsible are of the order of, or smaller than, a wave length of light. They may be the fibrils of the stromal collagen or the micelles of which these are composed, or they may be cellular inclusions. Clinically, the use of contact lenses produces a mild green deficiency which may become important under special conditions or to those already partially green blind.

G. *Entoptic Phenomena Kinetics.*

The whole train of scatter and diffraction phenomena suggests a change in refractive index in some or all of the structures of the cornea. We turned to a study of the entoptic fields[33] to investigate this question.

1. *Apparatus*

The primary source of the halometer was used and each subject viewed it from the usual observation point through a +20.00 D. lens.

2. *Procedure*

The subject wore a contact lens filled with 1.5% $NaHCO_3$. As the entoptic patterns arose, they were drawn at intervals during a run.

3. *Results*

The drawings made by B.D. as shown in Figure XX are striking and convincing. Similar patterns were mapped for the other observers, and all of these could be evoked repeatedly whenever contact lenses were worn.

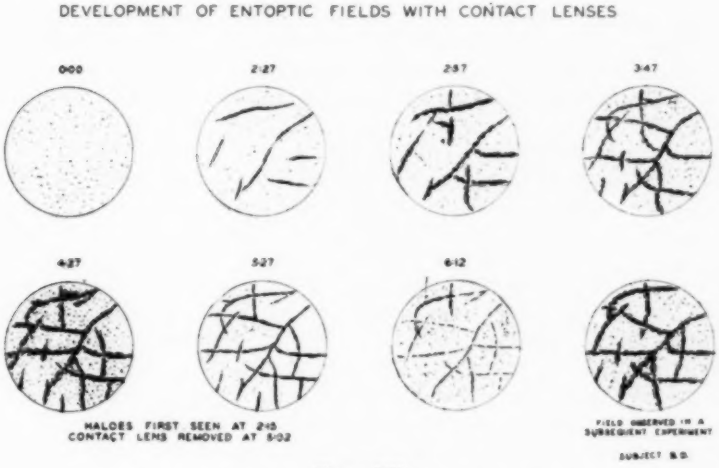

Figure XX
Development of Entoptic Fields with Contact Lenses.

4. *Conclusions*

The nature of the structures that produce these figures has not yet been determined, but careful slit lamp examination by Dr. Macnie did indicate a series of fissure-like lines in the endothelium which might be the cause of these patterns. Whether these lines are real or merely

shadows of structures situated anterior to the endothelium is not clear. Certainly, an edematous condition of the cornea might reasonably lead to such splitting of the endothelium; but it is extremely difficult to believe that the endothelial mosaic, or possibly Descemet's membrane, will repeatedly split in an almost identical fashion. If the seat of these lines is finally determined as lying in the endothelium and is definitely related to the observed entoptic fields, then an unsuspected factor in the structure of this lamina will have been disclosed. So far as the entoptic fields are concerned, the other fixed corneal structures that may be responsible are the corneal nerves themselves including the subepithelial plexus, or possibly the small canals[34] through Bowman's membrane by which they pass into the epithelial layers from the stroma. The possible existence of fixed channels which remain potential normally, but which dilate under conditions producing edema, may have to be examined in the new light of these patterns. A different constant pattern that can be elicited by rubbing the cornea with the lid has been attributed to fixed interstitial flow channels close to Descemet's membrane.[35] Histological studies by Fuchs[36] seem to indicate that the edematous invasion of the cornea in glaucoma is in part, at least, along the channels traversed by the corneal nerves that pierce Bowman's membrane.

H. *Determination of the Order of Magnitude of the Entoptic Patterns*

1. *Apparatus*

We devised a method of making these measurements which involved a slight modification of our microphotometer. The cross hairs in the tubular stop (Fig. I #5) were replaced by an ocular micrometer reticule (Fig. I #6), and placed in the anterior focal plane of the projection lens (Fig. 1 #9) of the illuminator. A green filter was placed in the filter box (Fig. I #4), and a small aperture (Fig. I #3) was turned into position to replace the slit.

2. *Theory and Procedure*

The theory of the measurement is based on the determination of a pair of rays that intersect at a selected point in the image of the entoptic bodies which would be formed by light passing outward from the eye. The parameters for each ray are obtained for a separate position of the slit lamp.

The method is indicated in Figure XXI. Let M represent the position of the effective source (the small circular aperture) for one of the two positions of the slit lamp. A_1 is the center of the projection lens of the illuminator, with a focal length of 100 mm. F_1 is the primary focal point of this lens. M'_1 is the projected image of M_1.

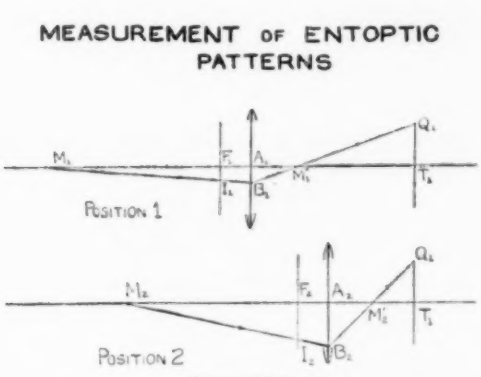

Figure XXI
Theory of Measurement of Entoptic Bodies.

T_1Q_1 is the image of the entoptic element to be measured, for light passing outward from the eye. It may also be considered as the virtual object whose real image for light passing into the eye is the entoptic element to be measured. Since all the effective light must pass through M'_1, this point becomes the center of perspective from which the entire visible pattern is optically projected.

Let B_1Q_1 be a ray passing through M'_1 and the virtual object point Q_1. Let I_1 be the point in which this ray intersects the primary focal plane in the object space. The point I_1 will appear superimposed on Q_1, since these two points are optically projected through M'_1 by a single ray. The point I_1 is a numbered point of the micrometer reticule, and its distance from the point F_1 can be read directly by the subject. Let

$$\angle T_1M'_1Q_1 = E_1$$
$$\overline{T_1Q_1} = s$$
$$M'_1T_1 = t_1$$

Then:

$$s = t_1 \tan E_1 \qquad (6)$$

But the angle $F_1A_1I_1$ also equals E_1 and therefore:

$$\frac{o_1}{f} = \tan E_1 \qquad (7)$$

where $o_1 = F_1I_1$ and $f = F_1A_1$ so that:

$$s = \frac{t_1 o_1}{f} \qquad (8)$$

Similarly for a second position

$$s = \frac{t_2 o_2}{f} \tag{9}$$

and

$$t_1 o_1 — t_2 o_2 = 0 \tag{10}$$

If the shift of the illuminator from position 1 to position 2 is denoted by d and always taken as positive, we have

$$t_2 = t_1 — d \tag{11}$$

and

$$t_1 o_1 — (t_1 — d) o_2 = 0 \tag{12}$$

or

$$t_1 = d \frac{o_2}{o_2 — o_1} \tag{13}$$

and similarly

$$t_2 = d \frac{o_2 — o_1}{o_1} \tag{14}$$

This distance of the entoptic image from the center of perspective M'_1 (for position 1) or M'_2 (for position 2) may be obtained from equations (13) and (14) respectively. The quantities o_1 and o_2 are merely the apparent sizes for some given element in the visual field projected upon the micrometer scale, and these are read off directly as though a scale were applied to the entoptic image. The quantity d is read off on the longitudinal scale along which the slit lamp is moved from position 1 to position 2. From the triangle $Q_1 M'_2 T_1$ it is plain that:

$$s = t_2 \frac{o_2}{f} \tag{15}$$

Where sufficient range of movement exists for the illuminator, the procedure for determining s may be simplified. When M′ lies in front of T_1 the entoptic pattern appears bright on a dimmer background. When M′ lies behind T_1 the pattern becomes complementary, that is, dim on a brighter background, and matters can be so arranged that the same elements subtend the same apparent size in the complementary fields. Under these circumstances $o_2 = —o_1$ and:

$$t_1 = \frac{d}{2} \tag{16}$$

while

$$t_2 = — \frac{d}{2} \tag{17}$$

that is, the position of the image of the entoptic bodies lies half way

between the positions M'_1 and M'_2 of the center of perspective, and the size of the image is given by:

$$s = \frac{d}{2} \cdot \frac{o_1}{f} \tag{18}$$

In our case, we did not have sufficient range to employ equations (17) and (18). We used equations (14) and (15).

3. *Results and Conclusions*

For one of our subjects, J. E., the following data for two separate determinations were obtained:

Determination:	I	II
d	1.31 cm.	2.07 cm.
o_1	0.343 cm.	0.290 cm.
o_2	0.518 cm.	0.523 cm.

The focal length of the projection lens is f = 10.0 cm. Using these quantities we obtain for determination II by equation (14):

$$t_2 = \frac{2.07 \times 0.290}{0.523 - 0.290} = 2.58 \text{ cm.} \tag{19}$$

and from equation (15)

$$s = \frac{2.58 \times 0.523}{10} = 0.135 \text{ cm.} \tag{20}$$

By a similar computation for determination I, s = 0.133 cm. with a mean value for both determinations of s = 0.134 cm. The distance of M'_2 from the vertex of the cornea was determined by racking in the slit lamp until M'_2 coincided with the pole of the cornea. In this case, the quantity turns out to be 2.40, so that the distance of the image of the entoptic bodies behind the front surface of the cornea would be some 1.8 mm. A similar computation for determination I gives a value of 1.3 mm. in front of the cornea. The mean value of both determinations, 0.25 mm. behind the front surface of the cornea, is probably much closer to the true value than the position given by either determination alone. If the refracting power of the front surface of the cornea is taken as 44 D., then the actual entoptic bodies would lie 0.34 mm. behind this surface if they are in the cornea, and the distance between the actual entoptic points responsible for the points chosen for measurement in the observed pattern would be less than 0.01 mm. smaller than s = 1.34.

These points were separated somewhat less than one-quarter of the field, so that the patterns as drawn represent a field whose diameter is about 4 mm. That these bodies lie in the cornea can be independently

established, for their position can be fixed by moving the center of perspective forward until the pattern disappears and the field seems to be uniformly illuminated. By observing with the microscope of the detector, this may be seen to occur in every case when M′ is in focus at the cornea. The change of pattern, from bright lines on a dim field to the complementary pattern of dim lines on a bright field, indicates that the entoptic bodies are of a higher relative index than the surrounding medium.[37] The drawings indicate that these patterns also arise uniformly over the effective zone of the cornea. When corneal lenses are used, these patterns do not appear. When "ventilated" lenses of the Dallos type are used, they do appear.

I. *Summation Kinetics*

The possibility, that more than one set of corneal elements contribute to the diffraction phenomena, suggested a series of halometry experiments designed to test this question. If the entire range of solutions used affected only one set of corneal elements, then the probability would be great that the halo kinetics differed only in rate, and that in time all curves would approach a single asymptote. If this were so, then an abrupt change of solution from an isotonic or hypertonic concentration to a hypotonic concentration, during the course of halo development, should materially reduce the average rate of development when the hypotonic solution is used initially.

1. *Apparatus*

The halometer.

2. *Procedure*

A contact lens with a hypertonic solution was worn for five or more hours. The lens was then removed and reinserted with a fresh solution.

3. *Results*

The halometry results obtained are plotted in Figure XXII. When distilled water was employed as the second solution, a striking and rapid increase in halo brightness, even beyond the rates obtained when distilled water was used initially, was found in every case.

4. *Conclusions*

This would seem to indicate that separate systems are involved when solutions of very low tonicity are used. Moreover, the markedly increased rate seems to indicate that wearing a contact lens even with isotonic or hypertonic solutions affects some property of the cornea or conjunctiva which may be related to permeability. Whether this change involves the cell membrane or whether it involves a loss of cohesiveness[38]

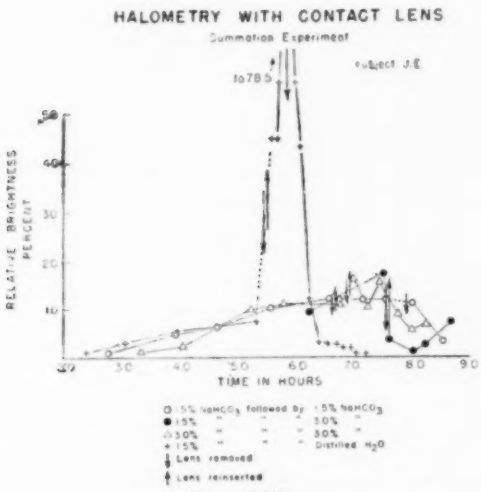

Figure XXII
Halometry Summation Experiment with Contact Lens.

between cells must remain a matter for further investigation. When the replacing solution was isosmotic or hyperosmotic with respect to the initial solution, the rate of halo development was reduced or even reversed. When the replacing solution was 1.5% $NaHCO_3$, the halo brightness remained constant for more than an hour. When it was 3%, the halo brightness dropped more sharply than when the lens was removed and the cornea was again bathed by normal effective lacrimal fluid. Some solution whose concentration lies between these two limits will be as effective as lacrimal fluid. If the tonicity of this solution were equal to that of effective lacrimal fluid, then the osmotic pressure hypothesis would gain additional support. If it were not, then it would be weakened. This experiment should be performed. Because of drainage, the initial slopes should be compared.

J. *Drainage by Fluorimetry*

1. *Apparatus*

Drainage determinations were made with the slit lamp microphotometer, slightly modified for this purpose. The modification consisted of the interposition of a set of Wratten filters, #s 35 and 45, in the path of the illuminator beam. They were arranged in a simple holder, by which they could be lowered as a unit into position in the filter box

(Fig. 1 #4) and as easily raised. In addition to these, a clear glass plate was left in the filter box to provide the internal reflections by which fine positioning was governed. These filters had a good minus green quality, with the maximum transmission in the blue, and slight transmission in the red for intensities as high as that of the slit lamp. A #58 Wratten filter was placed before the detector objective, as shown in Figure I #9. It transmitted only a narrow green band and was, therefore, practically the complement of the other two (#s 35 and 45). The three in combination transmitted only a very faint red to which our multiplier phototube, at highest sensitivity, showed a negligibly small response. With the slit lamp microphotometer in the standard position, these filters in place, and a subject properly positioned, only a negligible response of about 0.2 of a galvanometer scale division was obtained when the phototube was exposed.

2. *Procedure*

The matter is decidedly different, however, if the contained fluid is colored with fluorescein. The path of the illuminator beam through the fluid becomes luminous, and the galvanometer registers a considerable deflection when the phototube is exposed. Since light only from the contained fluid is visible during an exposure, the landmarks for positioning are absent. To avoid errors from this source, positioning is first controlled with the illuminator filters removed. The fixed glass plate provides the necessary internal reflections. The subject is requested to remain still, the "blue" filters are then quickly dropped into place, and the shutter is opened.

The fluorimeter was standardized for each subject by means of a series of fluorescein solutions prepared by dilution of an initial solution, and harmonically arranged with respect to concentration, that is, in a descending geometric series with a common ratio of ½. The diluent was a 1.5% $NaHCO_3$ solution. Each solution was given an index number n such that $C_n = C_0 2^{-n}$, where C_0 was the concentration of the initial solution and n was the index number of the solution whose concentration was represented by C_n. The initial or #0 solution consisted of seven drops of a 2% solution of sodium fluorescein in 30 ml. of 1.5% $NaHCO_3$ solution. Figure XXIII is a standardization curve for two of our observers. The solid line indicates the theoretical relation that would apply if fluorescence were strictly proportional to fluorescein concentration for a fixed depth of solution and a linear response of the detector. The circles indicate the obtained values; the open circles represent the data for one subject, and the solid discs for the other. They are in good agreement.

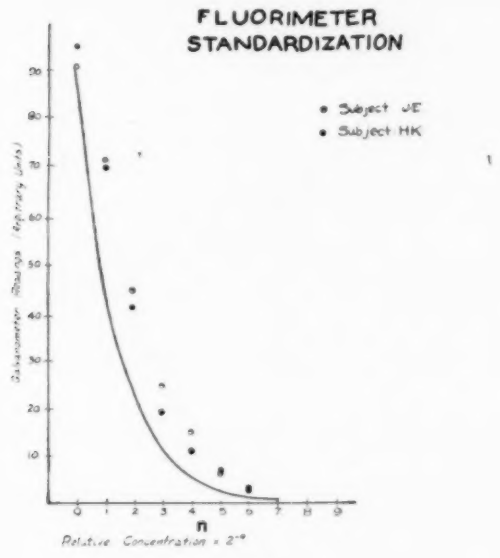

Figure XXIII
Fluorimeter Standardization.

3. *Results*

A composite plot of drainage kinetics for 0.125% $NaHCO_3$ and 1.5% $NaHCO_3$ is shown for our three subjects in Figure XXIV. The data for 1.5% $NaHCO_3$ represent nine runs; four for B. D., two for J. E. and three for H. K. The data for 0.125% $NaHCO_3$ represent eight runs; three for B. D., two for J. E. and three for H. K. The #0 solutions were used routinely. Contained hypertonic solutions are rapidly diluted to isotonicity with plasma in a matter of fifteen minutes to one-half hour.[39] Certainly drainage continued beyond this time, and must have been due to mechanical circulation of isotonic lacrimal fluid. If mechanical drainage is the predominant factor and if we assume that this proceeds at a constant rate, then, since the volume of the contained fluid is constant, we may write

$$\frac{dC}{dt} = kC \qquad (21)$$

where C is concentration and k is a constant. Upon integration we

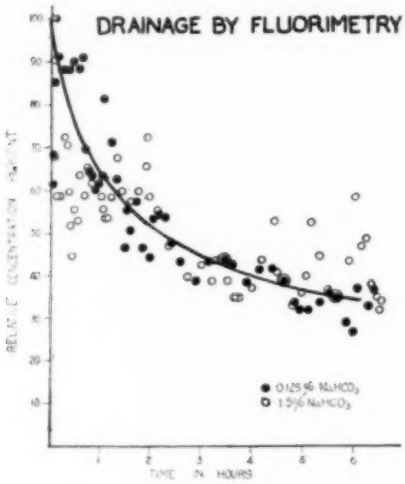

Figure XIV
Total Composite Plot for Drainage by Fluorimetry.

have:

$$\int_{C_0}^{C} \frac{dC}{C} = \int_{t_0}^{t} k\, dt \tag{22}$$

or

$$\log C \Big|_{C_0}^{C} = kt \Big|_{t_0}^{t} \tag{23}$$

If we take the concentration C_0 of the #0 solutions as unity and if t_0 is zero time, then we shall have at time t:

$$\log C = kt \tag{24}$$

where C is the concentration. We could find no value of the constant k for which the plot of (24) fits the obtained curve. If a value of k is taken, such that the initial rate of dilution computed by (24) is equal to the observed initial rate, then (24) gives a rate of dilution far in excess of observed values.

In order to obtain a good approximation it becomes necessary to assume that the rate of change of concentration is proportional to some exponential function of the concentration, rather than to the concentration itself. That is:

$$\frac{dC}{dt} = k_1 C^{k_2} \tag{25}$$

where $k_2 < 1$. In this form integration leads to an indeterminate expression involving the logarithms of negative quantities. If we change the argument to D such that $D = \frac{1}{C}$ the required integration can be readily performed. Physically, the substitution of the new variable involves working with dilution rather than concentration. We then have:

$$\frac{dD}{dt} = k_1 D^{k_2} \tag{26}$$

and

$$\int_{D_0}^{D} \frac{dD}{D^{k_2}} = k_1 \int_{t_0}^{t} dt \tag{27}$$

or

$$\frac{D(1-k_2)}{1-k_2}\Bigg|_{D_0}^{D} = kt\Bigg|_{t_0}^{t} \tag{28}$$

For $D_0 = 1$ and $t_0 = 0$ we obtain:

$$\log D = \frac{\log [k_1 (1-k_2)\, t + 1]}{1-k_2} \tag{29}$$

The curve corresponding to values of $k_1 = 0.015$/min. and $k_2 = -1.574$ is drawn through the observed data and fits fairly well.

4. *Conclusions*

The reduced rate of drainage with time indicated by the data is very likely due to the increasing conjunctival edema generally observed when standard contact lenses are worn. The curves for 0.125% $NaHCO_3$ and 1.5% $NaHCO_3$ are quite similar and indicate that the mechanical drainage of lacrimal fluid, rather than that due to diffusion of water across the cornea, is the predominant factor in the drainage kinetics. The observed variability is therefore capable of masking the discontinuities at the end of about 15 minutes which, if present, would indicate a drainage component due to diffusion across the cornea. The apparent separation of the data for 0.125% and 1.5% $NaHCO_3$ in the first half hour is due mostly to a single run for a single subject and is not present uniformly in the actual data. Nevertheless, since some such separation is to be expected on the basis of the osmotic pressure hypothesis, a further study of this point should be made. The pattern of drainage kinetics as a whole, however, tends to weaken the osmotic pressure hypothesis.

K. *Computation of Individual Correction Factors to Render Halometry Measurements Comparable*

The photometric matches as obtained by each subject are not com-

parable per se, since each is free to select the halo zone at which the match is made. But the measured relative* halo brightness of different subjects may be rendered comparable by the determination of individual correction factors, with which the relative brightness of the halo maximum can be obtained. This factor can be obtained by computation from the convergent infinite series which is the evaluation of Airy's diffraction integral.[40] This series may be arranged as follows:

$$I_B = kr^4\left[1-\frac{m^2}{2}+\frac{1}{3}\left(\frac{m^2}{2!}\right)^2-\frac{1}{4}\left(\frac{m^3}{3!}\right)^2+\frac{1}{5}\left(\frac{m^4}{4!}\right)^2\cdots\cdots\right]^2 \qquad (30)$$

where B is the angle of diffraction.** k is a constant depending on the units of brightness chosen, r is the radius of the diffracting particle or aperture, and

$$m = \frac{\pi r \sin B}{\lambda}$$

where λ is the wave length of light employed.

The intensity of the second maximum relative to that of the central or first maximum obtained from an evaluation of equation (30) is 0.01745. The correction factor C which we wish to determine is given therefore by:

$$C = \frac{0.01745}{I_{B_2}} \qquad (31)$$

where I_{B_2} is the intensity at the matching boundary of the comparison arc with respect to the central maximum. The value for each of our subjects is given in Table VIII.

Table VIII

Individual Correction Factors for Computing Maximum Brightness.

Subject	C
B. D.	1.46
J. E.	1.46
H. K.	1.52

L. *Determination of the Population Density of Diffracting Particles*

Assuming that the first lateral halo is due to particulate diffraction, the population density of the particles may be estimated. Let:

I_o = unit illumination for unit aperture at the maximum of the central retinal diffraction disc of an eye free of haloes.

*Relative to the maximum brightness of the comparison arc.

**That is, the angular subtense of the zone whose intensity is to be computed. In our case, we shall be concerned with the angle subtended at the observation point by the inner boundary of the comparison arc and the angular radius of each individual halo measured to the halo maximum.

s = great circle area of a diffracting globule, then

$$(I_s) = s^2 \tag{32}$$

where (I_s) is the illumination for an aperture of area s, and

$$(I_{B_{1s}}) = j_1 (I_s) = j_1 s^2 \tag{33}$$

where

$I_{B_{1s}}$ = the illumination at the second maximum, that is at the maximum of the first lateral halo, for an aperture of area s, and

j_1 = Lommel's constant 0.01745 for the relative illumination at the second maximum with respect to the first or central maximum.

By Babinet's[41] equivalence principle, $(I_{B_{1s}})$ will also be the illumination at the second maximum for a single particle with a great circle area s.

From equation (2) we have for unit aperture:

$$I_o' = (10^{-5.5})$$

and for an angle of azimuth A we will have a comparison arc brightness I_A such that:

$$(I_A) = (I_o')h_A = (10^{-5.5})h_A \tag{34}$$

where $h_A = \sin^4 A^*$;

and if, for simplicity, we assume that the diffracting particles are opaque and that

n = the population density of these particles, that is, the number per unit area, (assuming that the diffracting particles are in a single surface),

then the comparison arc would have its brightness reduced by a factor (1—ns), and we would have

$$(I_A') = I_A\ (1—ns) = (10^{-5.5})\ (1—ns)h_A \tag{35}$$

where

I_A' = the brightness of the comparison arc as seen by an observer with haloes, and

$$n = \frac{(I'_A)C}{(I_{B_{1s}})} = \frac{(10^{-5.5})\ (1—ns)\ h_A C}{j_1{}_s{}^2} \tag{36}$$

assuming that halo brightness is directly proportional to the number of effective particles and where C is defined as in equation (31), we have, finally,

$$n = \frac{F}{s\ (j_1 s+F)} \tag{37}$$

where

$$F = (10^{-5.5})\ h_A C.$$

*By the law of Malus[42] the fourth, rather than the second, power arising because of the presence of two fixed polaroids.

When reasonable numerical values are assigned to these quantities, such as:

$$s = 64\pi \text{ microns}^2$$
$$h_A = 0.25$$
$$j_1 = 0.01745$$
$$C = 1.5$$

then, $$n = \frac{240 \text{ particles}}{\text{mm}^2}.$$

M. *Histology.*

1. *Experimental Animals*

Twenty rabbits, two dogs, one rhesus monkey and 10 guinea pigs were used. All were fitted with contact lenses either prepared from impressions of their eyes or from the total collection of lenses at the laboratory.

TABLE IX

Histology.

Animal #	Solution	Time	Termination	Fixative	Stain
R 13*	Dist. H_2O	4 hrs. 45 min.	Air Injection	Zenker's	H & E
R 30*	Dist. H_2O	6 hrs. 15 min.	Air Injection	Bouin's	H & E
R 31*	Dist. H_2O	17 hrs. 15 min.	Air Injection	Bouin's	H & E
R 1*	Dist. H_2O	6 hrs. 00 min.	Air Injection	10% F	Mc J
R 51	1.5% $NaHCO_3$	5 hrs. 55 min.	Air Injection	10% F	Mc J
R 28	0.5% $NaHCO_3$	8 hrs. 00 min.	Air Injection	10% F	Mc J
R 25	0.5% $NaHCO_3$	5 hrs. 20 min.	Air Injection	10% F	Mc J
R 41	0.5% $NaHCO_3$	2 hrs. 40 min.	Air Injection	10% F	Mc J
R 2*	1.5% $NaHCO_3$	6 hrs. 45 min.	Air Injection	Regaud's	AAF, MG, & M
R 24	0.5% $NaHCO_3$	2 hrs. 00 min.	Air Injection	Regaud's	AAF & MG
R 26	0.5% $NaHCO_3$	4 hrs. 00 min.	Air Injection	Regaud's	AAF & MG
R 23	0.5% $NaHCO_3$	5 hrs. 55 min.	Air Injection	Regaud's	AAF & MG
R 32	0.5% $NaHCO_3$	7 hrs. 55 min.	Air Injection	Regaud's	AAF & MG
Dog L*	1.5% $NaHCO_3$	6 hrs. 30 min.	Nembutal	Regaud's	AAF, MG, & M
GP 6	none	(control)	CO**	Regaud's	AAF & MG
GP 2	Dist. H_2O	0 hrs. 10 min.	CO**	10% F	Mc J
GP 1*	1.5% $NaHCO_3$	6 hrs. 30 min.	CO**	Regaud's	AAF, MG, & M
GP 3	1.5% $NaHCO_3$	7 hrs. 25 min.	CO**	Regaud's	AAF & MG
GP 4	1.5% $NaHCO_3$	6 hrs. 05 min.	CO**	Regaud's	AAF & MG
GP 5	1.5% $NaHCO_3$	6 hrs. 01 min.	CO**	Regaud's	AAF & MG
GP 122	1.5% $NaHCO_3$	7 hrs. 00 min.	CO**	none	JGB

*Procedures completed.
**CO = carbon monoxide (asphyxiation).
I. Animals. A. R = rabbit. B. GP = guinea pig. II. Fixative. F = formalin. III. Stains. A. H & E = hematoxylin and erythrosin B. B. McJ. = McJunkin's benzidine. C. AAF = Altman's acid aniline fuchsin. D. MG = methyl green. E. M = Masson's. F. JGB = Janus Green B.

2. *Procedure*

Table IX indicates the procedures followed. McJunkin's benzidine method for peroxidase was used to differentiate neutrophils from other possible polymorphonuclear leucocytes that might invade the

cornea. Altman's acid aniline fuchsin and Masson's are mitochondrial stains. These stains were selected on the assumption that mitochondria would be more noticeably affected by hydration than other cellular elements. Janus Green B was tried on one guinea pig, #122, for the same reason. Only rabbits maintained fixation with sufficient steadiness to permit measurements of corneal scatter with a precision of 10 per cent or better. Four of these, #s 24, 26, 23 and 32, wore lenses with 0.5% $NaHCO_3$ for 2, 4, 6 and 8 hours respectively and their eyes were then fixed in Regaud's. Three, #s 28, 25 and 51, also wore lenses with 0.5% $NaHCO_3$ for 8, 5⅓ and 2⅔ hours respectively and their eyes were then fixed in 10% formalin. All seven showed about a 100 per cent increase in corneal scatter after 6 hours with 0.5% $NaHCO_3$. These animals may therefore be considered as standardized with respect to corneal scatter.

3. *Results*

Although we have prepared 21 pairs of eyes for study, we have had time only to study representative specimens as pilot experiments. All the rabbits stained with hematoxylin and erythrosin B showed invasion by polymorphs. Rabbit #31 showed about 20 times as many polymorphs in the contact lens eye as in the control eye, but the increase was mainly in the periphery of the cornea, and no evidence of extensive invasion was found in guinea pigs. Rabbit #1, stained by McJunkin's method, indicated that these were most probably neutrophils. Rabbit #2 showed a differential staining reaction. The intermediate polygonal cells of the epithelium of the contact lens eye took up more of the fuchsin than the other eye. The same was true for guinea pig #1. Masson's stain did not present any marked differentiation in any animal, and differential affinity for acid fuchsin was not evident in the dog's eye. The experiment with Janus Green B on guinea pig #122 gave no clear differentiation.

4. *Conclusions*

In the rabbits' eyes white cells invaded but, since little if any invaded in our guinea pig and dog, extrapolation to human eyes should be cautious, especially since all our guinea pigs and both dogs showed greater corneal scatter than did the rabbits. The increased affinity of epithelial polygonal cells of contact lens eyes for acid fuchsin in both rabbit and guinea pig may indicate that these cells are uniquely susceptible to trophic changes induced by wearing contact lenses and form a uniform stratum characterized by a common metabolic state, intermediate between that of the basal and superficial layers. In any case, these conclusions must be considered as tentative, awaiting confirmation by

study of all the material.

N. *Search for Haloes in Animal Eyes*

If haloes develop in animal eyes, they can only be demonstrated by objective means. Such a demonstration is essential, however, if the results of animal experimentation are to have any validity for man.

1. *Apparatus*

A high intensity point source was placed 4.5 meters from a microscope whose substage condenser was removed. The plane substage mirror reflected a beam of light from the source up through the microscope. A 48 mm. objective and a 5X ocular were used. A rubber dam, perforated to receive a contact lens, was placed on the stage with the perforation center on the optic axis.

2. *Procedure*

An enucleated eye that had worn a contact lens was fenestrated at its posterior pole by means of a 4 mm. trephine. A transparent screw plug, patterned on those used by Arruga in retinal detachment operations, was driven gently into the aperture and the hypodermic needle of a simple water (saline) manometer was plunged through the sclera. The globe rounded out in about one minute and maintained an intraocular pressure of between 25 mm. and 30 mm. Hg. The globe was then set into a contact lens filled with normal saline, with its cornea centered in the lens. The posterior scleral aperture was then focused with the microscope, and the field carefully studied.

3. *Results*

Two rabbits were investigated in this way. In each a rather extensive central aureole, centered on the image of the point source and edged with a chromatic border, was seen in that eye which had been enucleated and tested first. The contact lens eye was the first eye studied in only one of the two animals. Optical imagery remained excellent throughout.

In earlier experiments, before the plugs and manometer were introduced, brilliant haloes could be induced in such fenestrated eyes by filling the contact lens with a very dilute solution of blood, or placing a synthetic diffraction plate in front of the contact lens. In these eyes optical definition remained excellent also, and if the primary source of the halometer were used as a point source and its image centered in the scleral window then the comparison arc was also clearly discernible, although its brightness was reduced to the level at which a halo just rises above threshhold in a human observer. These results were obtained in rabbits, guinea pigs and a dog.

4. *Conclusions*

Contact lenses do not induce the appearance of diffraction haloes when worn in the eyes of rabbits, guinea pigs and probably dogs, so far as our experiments indicate. Possibly the optical differentiation, upon which the appearance of haloes depends, rapidly fades post mortem, although the optical integrity of the eye is maintained sufficiently well to project such haloes when induced by synthetic means. Schiotz and Druault[43] have reported seeing brilliant haloes through the excised corneas of normal rabbits' eyes when properly mounted and immersed in normal saline. Perhaps their results were obtained because of the complete disorganization of the eye as a whole that their method requires. Their results would then have little bearing on the haloes induced by contact lenses.

V. DISCUSSION

A. *Phase Relations*

The clear difference between the simultaneous kinetics of scatter and diffraction contained in our results indicate that these phenomena are induced by separate physical systems. The marked phase differences that arise between them under special conditions strongly confirm this view. Corneal lenses of the Tuohy type and ventilated lenses of the Dallos type induce little or no diffraction, but show considerable scatter. The performance of these two types is not invariantly related, however, for while entoptic fields do not develop with corneal lenses, distinct patterns develop with the Dallos type. The kinetics of entoptic changes are, therefore, not constantly related to those of the primary phenomena of scatter and diffraction. This view is confirmed by the phase differences exhibited when distilled water is employed. Haloes appear very rapidly and rise to considerable brightness before any subjective evidence of entoptic patterns appears.

Our results indicate, moreover, that the observed diffraction may itself be induced by more than one physical system, since the ratio of the diameters of the observed first and second lateral haloes differs significantly from that expected for a set of haloes induced by particles of uniform size. The results of our summation experiments indicate that solutions of very low tonicity may induce diffraction in two sets of elements different from those involved when solutions of higher tonicity are used. The particle sizes in this case are respectively very nearly alike, however, since the diameters of the observed lateral haloes remain independent of the osmotic pressure of contained solutions. Histologically, this need only mean that two sets of elements, of different biochemical

character but of equal cell and nucleus size, are involved. The separate grouping of the kinetics of the very low tonicity and higher tonicity curves points to a similar relationship in the case of scatter. The cornea easily provides such an anatomical diversity. Alternative possibilities have already been discussed in connection with the corresponding experiments.

The size of the particles responsible for the first lateral halo has been computed as 16.1 microns. If the observed second lateral halo should prove to be the first halo of a separate diffraction system, then the corresponding particle size would have to be of the order of 8.4 microns. Particles of this size are too large to explain the differential scattering measured on the anomaloscope. This fact, and the close correspondence between the scatter measured objectively by the microphotometer and that measured subjectively by the anomaloscope, indicates that the same systems may be involved in this case. If this is so, then the supposition that the diffracting particles make a significant contribution to the scatter kinetics of low tonicity solutions must be discarded as a possible explanation. This type of scattering has been reported for excised corneas.[44]

B. *The Chloride Shift*

The chloride shift in blood depends primarily on a change in the ratio of K^+ divided between the non-diffusible Hb molecule and HCO_3^-. If we define this ratio as $P = \frac{KHb}{KHCO_3}$ then P will be greater for oxygenated than for reduced blood, since oxygenated blood has the higher acidity and greater capacity to bind base and reduce osmotic pressure. A supply of O_2 is therefore necessary to maintain erythrocytes deturgesced to their minimum physiologic volume. Let us speculate further and assume a corneal mechanism for maintaining deturgescence during anaerobic phases of glycolysis such as in sleep. If, however, some external factor such as limbal congestion provoked by a contact lens increases the rate at which CO_2 or other acids are released, then the supplemental external respiration of the cornea may become essential to continued transparency. Possibly the effectivity of ventilated lenses lies in the supply of this additional oxygen, while without it even highly buffered solutions do not suffice; and only solutions of high tonicity can affect the necessary dehydration. Alternatively, lenses that exert some pressure on the cornea and behave as a pressure bandage may prevent edema.* Perhaps on this basis the chloride shift hypothesis should

*Pressure exerted on reversibly clouded corneas has been reported as effective in restoring transparency[46].

not be completely set aside.

C. *Osmotic Pressure.*

The weight of evidence indicates that osmotic pressure is an important factor in maintaining the normally constant state of corneal hydration.[45] Our results, indicating increased delay in halo development with increasing concentration, and increasing rate of recession with increasing concentration of the replacement solution in our summation experiments, as well as the similarity of the diffraction kinetics for solutions isosmotic with 1.5% $NaHCO_3$ but of widely differing buffer capacities, all tend to confirm this hypothesis* and, therefore, the Cogan-Kinsey theory as well. But the departure of the actual rates of halo development from those predictable by this theory, the relative differences in these rates for solutions isosmotic with 1.0% and 0.5% $NaHCO_3$, the presence of adaptation effects such as those shown by our subject B. D., the induction of haloes on exposure to ultra violet radiation observed by Duke-Elder, and the very rapid appearance of haloes in our subject B. D. when attempting to use a boric acid solution isosmotic with 1.5% $NaHCO_3$ as well as the appearance of "blue haloes" in atabrine workers reported by Ida Mann, the induction of haloes by exposure of the cornea to CO_2 in relatively high concentrations, and by various agents already mentioned, all indicate that the simple basis provided by the Cogan-Kinsey theory may not be sufficient. Some other factors will need to be added in the case of contact lenses, however well the theory may apply to more normal situations.

D. *The Invasion Hypothesis*

The histological findings in rabbits' eyes furnish the only evidence we have found in direct support of this hypothesis. The constancy of halo brightness for variable pupillary areas is direct and convincing evidence opposed to it, unless the entoptic patterns observed are channels by which large numbers of blood elements may invade and from which they may then diffuse uniformly over the effective zone of the cornea.

E. *Proposed Applications and Experiments*

The apparatus and techniques we have developed provide a biophysical framework within which any consistent explanation of these phenomena and their underlying corneal physiology must fit. They have also provided a means of comparing the clinical performance of contact lenses.**

*The importance of osmotic pressure in contact lens solutions has previously been emphasized by others[47].

**They are now being so employed under Major McGraw by the United States Army at its Medical Field Research Laboratories at Fort Knox, Kentucky.

As in any investigation, certain aspects of our original research program have had to be deferred for lack of time or facilities. These include a study of the effect of temperature and pressure on kinetics, as well as continuous measurements of pH changes while a lens is worn. The apparatus we designed for the pH measurements is now in an advanced stage of development.

Among other useful clinical applications of contact lenses, Sattler[48] has reported a reduction in intraocular pressure of glaucomatous eyes when these lenses are worn. This may be related to the change in permeability indicated in our summation experiments. If the day to day stability of the slit lamp of our microphotometer can be improved, then perhaps studies of corneal scatter constancy may play a part in the diagnosis of suspected glaucoma by providing a delicate method of following changes in transparency. Since the rate of development of color deficiency follows the scatter kinetics, the anomaloscope by which the former is measured may yield the same information with greater ease. Summation patterns possibly related to permeability changes may also serve as diagnostic aids.

F. *Conclusion*

At the present time and as a result of these studies, we agree with Hugh Davson[49] that we are not yet in a position to elaborate a comprehensive theory of corneal metabolism, water balance, and transparency, but that such a formulation must await additional knowledge of the physico-chemical parameters involved. We hope that this investigation has made a contribution to our knowledge of some of these parameters.

VI. SUMMARY

1. Two instruments, a slit lamp microphotometer and a halometer, were devised. Corneal scatter could be measured objectively with the former. Diffraction halo brightness could be measured subjectively with the latter.

2. Both phenomena, scatter and diffraction, were induced when contact lenses were worn by human subjects. They increased simultaneously with time, but at respective rates which were not invariantly related.

3. In addition, striking entoptic patterns, localized in the cornea, developed as lenses were worn. They were unique and constant for every observer, but they developed at rates which were not invariantly related to those of scatter and diffraction.

4. The wide phase differences that could be induced between the

kinetics of these three optical effects indicated that a complex of anatomical and physiological systems was involved.

5. Subjective measurements with an anomaloscope indicated that scatter was of the differential type. The scattering particles, therefore, had a diameter of the order of a wave length of light or less. The fibrils of corneal stroma collagen, whose diameter is about one micron, or the micelles of which they are composed, are the most likely elements responsible for the scatter.

6. With intense sources, two lateral haloes were simultaneously present as some types of lenses were worn. Their angular diameters did not correspond, however, with those of the orders of a single system of Fraunhofer diffraction haloes projected by a theoretically perfect optical system.

7. This discrepancy in the diameters of the observed haloes could mean that:

a. Two separate sets of particles were involved. One set with a uniform diameter of 16.1 microns would produce the smaller halo. The other set with a uniform diameter of 8.4 microns would produce the larger halo.

b. The observed diffracting angles required to produce the optical path differences to which the observed halo diameters correspond may be different, for the eye, from those required of a perfect system.

c. The diffraction may not have been of the particulate but, possibly, of the laminary variety.

8. Over a wide range, scatter remained independent of osmotic pressure and buffer capacity of the solutions contained between the contact lens and cornea.

9. The time of appearance and rate of development of diffraction haloes was strongly influenced by the osmotic pressure of contained solutions, but not by their buffer capacities.

10. The respective rates of drainage of two contained solutions, whose osmotic pressures were in the ratio of 12:1, remained generally similar over a period of six hours. This would seem to indicate that the mechanical circulation of lacrimal fluid was the predominant component in drainage kinetics.

11. Some slight indication existed in the data that the more hypertonic solution, which was 1.5% $NaHCO_3$, drained more rapidly during the first half hour. This, if significant, would mean that a component due to diffusion across the cornea, along an osmotic pressure gradient, was present.

12. The marked influence exerted by osmotic pressure on halo

kinetics and possibly on drainage tends to support the hypothesis that abnormal corneal turgescence due to a displacement of the steady state of corneal hydration is the physical mechanism responsible for the observed optical effects. Such a mechanism is based on the Cogan-Kinsey theory of corneal hydration, and evidence of its existence lends support to that theory.

13. A study of the total kinetics of scatter, diffraction, and drainage indicated, however, that the simple basis provided by this theory is not sufficient. Some other factors are involved in the case of contact lenses, however well the theory applies under more normal conditions. Determination of the nature of these factors will probably provide additional insight into the involved physiology of the cornea.

14. Biomicroscopy revealed that a uniform cloud of refractile bodies arose in increasing numbers as lenses were worn by our subjects. They had an apparent diameter of about five microns, and might have been specular reflections from larger elements directly responsible for some of the diffraction.

15. Histological studies suggest that leucocyte invasion of the peripheral zones of the corneas occurs in the eyes of rabbits fitted with contact lenses containing distilled water. Such an invasion has not been found in guinea pigs, however. Studies of the relation between pupil size and relative halo brightness indicate that such an invasion into the optical zone of human corneas is not likely.

16. A search for haloes in the eyes of our experimental animals did not disclose them. They are probably not induced in their eyes by contact lenses. Histological studies of their eyes in connection with the effects of contact lenses should, therefore, be interpreted with great caution.

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FURTHER COMMENTS ON LUNEBURG'S ANALYSIS OF BINOCULAR VISION*

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In a recent paper[1] the writer presented an analysis of binocular vision and in a subsequent paper[2] compared his own analysis to that of Luneburg.[3]

This paper is presented to call attention to several errors in the equations which resulted from omissions in transcribing, and which were not detected in the final proof reading. Additional comments are also made concerning the relation of the two analyses.

CORRECTIONS FOR THE FIRST PAPER[1]

P. 547, Equation 32. Change ds to ds^2.

P. 549, Equation 34. Change to read as follows:

$$\bar{\gamma} - \gamma_2 = \tan^2 \phi \left[H_1 + \frac{a \ (\cos^2 \phi)}{\bar{p} \ (1 + \cos \phi)} \right] . \quad (34)$$

P. 549, Equation 35. Change to read as follows:

$$\bar{\gamma} - \gamma_2 = \tan^2 \phi \left[H_1 + \frac{a}{2 \ \bar{\rho}} \right] . \quad (35)$$

P. 549, Second line above Equation 36. Change H to H_1 and ρ to ρ_1.

P. 533, Fourth line from bottom. Change P' to $\overline{P'}$.

Fig. 16 B. Change θ to θ'.

P. 551, Line 7. Change P' to P'_3.

P. 551, Equation 39. Change γ_1 to γ_3.

P. 552. The line following Equation 44. Change to read as follows: The ratio α / β' approaches unity as the distance of the disk increases. Even at a distance of 40 cm. the ratio is as close to unity as 1.0028 when $a = 60$ mm., etc.

CORRECTIONS FOR THE SECOND PAPER[2]

P. 4, Equation 5. A term ρ^2 should be added to make it read

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$$ds^2 = \frac{4\ K_2^2\ \rho^2}{(\ 1 + K_1\ \rho^2\ )^2}\ (\ \sigma^2\ d\ \gamma^2 + d\ \phi^2 + \cos^2\phi\ d\ \theta^2). \quad (5)$$

The statement was made that this equation would not apply when ϕ and θ were defined as angles of azimuth and elevation. That statement is not true; the equation does hold for large as well as small values of θ.

P. 7, Equation 12. The term d ϕ^2 should be changed to d ϕ''^2 and brackets should be added to make the equation read

$$ds''^2 = d\rho''^2 - \frac{K_2^2}{K_1}\ \sinh^2\left[\ \rho''\ \frac{\sqrt{-K_1}}{\rho}\ \right]\ d\phi''^2\ . \quad (12)$$

P. 9, Equation 16. The symbol a should be substituted for 2.

P. 18, Equation 18. Radical signs and brackets should be added to make the Equation read:

$$\frac{ds}{\rho''} = \frac{1}{\rho''}\ .\ \frac{K_2}{\sqrt{-K}}\left[\ \sinh\ \rho''\ \frac{\sqrt{-K_1}}{K_2}\ \right]\ d\phi\ . \quad (18)$$

The writer could have simplified matters by using the same symbols P'', ρ'' and ϕ'' to represent points and coordinates in visual space for his own analysis as well as for Luneburg's and also by using the same diagram (Fig. 5) to represent visual space.

This would make it more apparent that the same equation

$$\phi'' = \phi \quad (10)$$

can be used for relating the perceived direction of an object to its position in physical space.

It would also make it apparent that the same metric [Equation (12) above] applies to both analyses. The only difference is that the writer has assigned a specific value of zero to K_1.

Furthermore when K_1 is small or is equal to zero, Equation (18) above reduces to

$$\frac{ds}{\rho''} = d\ \phi''$$

which expresses the writer's concept of the relation between perceived size and perceived distance.

It turns out therefore that aside from assigning a specific value of zero to K_1, the major difference between Luneburg's analysis and that of the writer is that the writer has presented a new distance function

$$\frac{1}{\rho''} = K + \frac{H_1\ \tan^2\phi}{2} + \frac{\gamma}{a} \quad (16)$$

to replace the one used by Luneburg, namely

$$\rho'' = \frac{K_2}{\sqrt{-K_1}} \log \frac{1 + \sqrt{-K_1}\, e^{-\sigma}\ (\gamma + \mu)}{1 - \sqrt{-K_1}\, e^{-\sigma}\ (\gamma + \mu)},$$

which represents a combination of Equations (3) and (9) in the second paper. In the writer's analysis ρ'' is dependent upon both ϕ and γ but in Luneburg's analysis it is dependent only upon γ.

When ϕ is equal to zero and $\frac{1}{x}$ is substituted for $\gamma/2$, Equation (16) reduces to

$$\frac{1}{\rho''} = k + \frac{1}{x} \qquad (17)$$

which is identical with the equation used by von Helmholtz[4] and von Kries[5] for expressing the relation between perceived and physical distance.

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ANNOUNCEMENT

I. E. S. ANNOUNCES NEW HANDBOOK

The Illuminating Engineering Society announces the publication of the 1952 Lighting Handbook. This new manual takes the place of the 1947 edition which has been entirely revised to incorporate in the new volume all of the latest developments in lighting techniques, their theory and application. The new volume is illustrated containing 657 photographs, sketches and charts. This work will prove of value to optometrists engaged in industrial eye care programs. The book may be secured through the Illuminating Engineering Society, 1860 Broadway, New York 23, New York, ($8.00).

COMMENTS ON LUNEBURG'S AND FRY'S ANALYSIS OF VISUAL SPACE*

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Recently Fry has propounded an analysis of binocular vision in which he applies only the concepts of Euclidean geometry.[1] Within the limits which he specifies, his analysis is correct. But when he contrasts his view with Luneburg's,[2] Fry seems to imply that one may legitimately choose between them. Boeder has pointed out that there is no conflict between the two analyses and has indicated the restrictions to which Fry's analysis is subject.[3] In his second paper,‡ however, Fry seems to imply that the two analyses are comparable. Actually, he deals only with a special case which can be subsumed under Luneburg's general thesis. If he prefers to analyze this special case in terms of Euclidean concepts that is permissible. But to compare his analysis with Luneburg's has point only if one would also defend comparison between one and many.

Nearly a century ago William Whewell, master of Trinity College, Cambridge, produced a comprehensive history of science while he sought to determine just how science had developed. One of his great contributions, from a practical point of view, was recognizing some of the characteristics of good and bad hypotheses as revealed by the History. Later history has confirmed his view that fruitful hypotheses show certain characteristics which distinguish them from erroneous or inadequate hypotheses. I cannot cite these exactly but later writers on scientific method have followed this lead. It has become almost automatic for those interested in the philosophy of science to test new developments in fields with which they are not specifically familiar by asking such questions as the following:

> Does the hypothesis account for all known facts?
> Does the hypothesis suggest new experiments and successfully predict their outcome?
> Does the hypothesis provide explanation for data which were not taken into account in its original formulation?

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‡Editor's Note: A third paper by Fry, "Further Comments on Luneburg's Analysis of Binocular Vision," appears in this issue.

Is the hypothesis of maximal generality, simplicity and intelligibility?

Let us apply these criteria to the analyses of binocular vision proposed by Luneburg and by Fry. No exhaustive study is necessary for the check which is outlined below. A cursory reading of the papers by the two authors justifies the following evaluation, provided one takes the mathematics on faith, as most of us shall have to do.

First, does the hypothesis account for all the known facts? Luneburg's analysis accounts for the Dartmouth demonstrations which inspired his effort, and also indicates why a Euclidean geometry appears adequate for much of our experience. Fry's analysis explains only a segment of the latter, for he specifies that the eyes are held steady, fixating a point in the median plane.

Second, does the hypothesis suggest new experiments and successfully predict their outcome? Luneburg designed an original configuration derived from his analysis.[4] From this, binocular observers usually derive the predicted impression. A portion of this configuration has sufficed to excite the appropriate impression even in young children.[5] Can anything new come out of Fry's analysis?

Third, does the hypothesis provide explanation for data which were not taken into account in its original formulation? Luneburg for the first time explains the puzzling results in the alley experiments of Blumenfeld. He mentions this in his first publication, but it is my impression that formulation of his hypothesis preceded his acquaintance with Blumenfeld's work. Perhaps his friend, Boeder, could make a definite statement on this point. In any case, contrast this with Fry's statement, "In the writer's analysis, the two sets of alleys should agree and the discrepancy has to be accounted for in terms of the difference in eye movement patterns or changes in the constant k during the experimental determination of the two types of alleys."[6] This is a typical *ad hoc* comment.

Finally, is the theory of maximal generality, simplicity and intelligibility? Luneburg's theory is general. He considers observation with moving head and symmetrical convergence, and with head fixed and asymmetrical convergence.[7] Combinations of these conditions are apparently omitted for the sake of simplicity in illustration of his thesis. The rigid conditions specified by Fry have already been indicated. His analysis requires essential additions and elaboration to cover the normal conditions of observation, for which provision is implicit in Luneburg's theory.

The simplicity of Luneburg's theory is represented by the statement that the metric of visual space is hyperbolic. The conclusions to be derived from this view can only be drawn by mathematicians who are competent in handling non-Euclidean concepts. The processes which they employ will not be simple, and much ingenuity may be required in exploring the full implications of this thesis. But Luneburg has already shown, before his untimely death, that purely deductive, mathematical reasoning produced significant conclusion. Fry, on the other hand, maintains the view that visual space is Euclidean, the view which has been held traditionally and whose implications have been pretty thoroughly explored. He has suggested no new approach which seems likely to provide solutions where application of this concept has failed in the past. He merely simplifies a problem until an inadequate theory suffices to provide a solution there. When Fry attempts a new problem, he will have to add, I believe, a new set of restrictions. This is the antithesis of the simplicity referred to in the criterion by which a good hypothesis is judged.

With respect to intelligibility similar comments are in order. Luneburg's theory indicates why the Euclidean geometry is adequate within restricted limits and also where it fails. Fry, by restricting himself to a Euclidean geometry, also restricts the field of applicability of his analysis to a highly abstract situation, not representative of actual visual experience. Spatial relations as ordinarily perceived, with roving eyes and moving head, remain unintelligible. Luneburg showed clearly that his view includes explanation of data gathered under more normal conditions of observation. He has brought the Dartmouth demonstrations and the alley experiments into the realm of intelligibility for the first time. Is it likely that this is all that will be accomplished when his approach is more fully explored?

Having been privileged to study under Fry, and having high regard for his work in many areas of investigation, it is with regret that I see him stubbornly defending a method of attack which is so limited, but which he somehow believes is comparable to the general theory proposed by Luneburg. Convenience in calculation may be a merit in Fry's method, but this is not an essential aim in any valid analysis of binocular vision. Understanding of our spatial interpretations of all visual experience is the ultimate goal: Luneburg's analysis contributes here.

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ANNOUNCEMENT

ACADEMY "CALL FOR PAPERS"

Dr. Meredith W. Morgan, Jr., chairman of the Papers and Program Committee, American Academy of Optometry, has issued the annual "Call for Papers" for the coming meeting of the Academy at Rochester, New York, December 6, 7, 8, 9, 1952.

Academy members who wish to present a paper at this coming meeting should now send the title of the paper and the suggested Academy section or general session meeting at which the paper is to be read. Papers are limited to a reading time of not-to-exceed 30 minutes. An abstract of the paper must be submitted to the committee before October 1, 1952. The preliminary information now requested should be sent immediately to Dr. Meredith W. Morgan, Jr., School of Optometry, University of California, Berkeley, California.

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COMMENTS ON POSSIBLE PSYCHOLOGICAL CAUSES OF STRABISMUS

In a recent lecture in which subjects for clinical research in optometry were reviewed, Eric Bateman, secretary of the British Chapter of the American Academy of Optometry, calls our attention to several of the various problems of psychology which have an impact on vision or binocular poise. Bateman points out that too many writers in the optometric literature have lead the way in this direction for the subject to be lightly dismissed or without now discussing the mental mechanisms involved in the production of symptoms, some of which may be of ocular or visual origin. Bateman particularly refers to such aberrations which develop in the life of the individual—usually post-natal.

He finds these aberrations falling into two groups, the psychosis and the neurosis. He believes that the latter is of major concern. Bateman

defines a neurosis as the inability to face reality in one or more fields of personality which would normally be open. In consequence, the emotional energy of the patient is held down. Bateman points out that this condition arises in the following manner. The malleable emotional character pattern is formed during the first five years or so of life. As time goes on, the more specifically human aspects of personality develop —knowledge, and therefore reason, moral consciousness, etc.

If for some reason—usually parental in cause—an emotional fear, horror, or hate is developed at the infantile level, in the interest of nurture, safety or the desire for security, this "horror-focus" is pushed down to the subconscious mind and therefore genuinely forgotten. When in due course the personality and character develop, it is found that symptoms arise because the emotional development is not in harmony with the rest of the personality and the cause is quite unknown to the patient involved.

Bateman claims that if a person cannot "face" life, because of some hidden fears he has to produce a seemingly good reason to mollify his ego. Hence, certain well known symptoms already are known to be in part secondary to a psychological primary cause. Bateman points out that these include certain groups of strabismic cases and patients suffering from amblyopia ex anopsia. He claims that this can be proved, at least in certain cases by complete cures which follow suggestion under hypnosis.

Bateman defines hypnosis as the short circuiting of the ego down to and including the level of the will, thus enabling the psychiatrist to obtain direct access to the subconscious mind of the patient.

It must be pointed out that Bateman makes it quite clear that he is not claiming that every case of strabismus is caused by a neurosis. He does, however, claim that in some of these patients the first cause of the problem in binocular vision is a neurosis.

Bateman's paper will be published in full in the *British Journal of Physiological Optics*. The author, who follows the principles of orthoptic techniques as originally proposed by Cantonnet and more recently reviewed and elaborated on by Giles, stresses the fact that we as optometrists must be aware of the psychological implications of orthoptic work as well as those dealing in the physiological and anatomical realm of binocular vision. This portion of Bateman's paper also clearly brings out the point that optometric professional training does not qualify the practitioner as a psychologist or a psychiatrist, and further brings out the fact that in stubborn strabismic cases which do not respond to presurgical orthoptic care in the hands of the optometrist there should be

professional consultation in the patient's behalf with ophthalmology, pyschology and psychiatry.

CAREL C. KOCH

TRANSACTIONS OF THE AMERICAN ACADEMY OF OPTOMETRY

A department devoted to announcements, reports, appointments, organization data, news, professional problems and ideals, as these relate to the Academy.

NEW MEMBERS OF THE ACADEMY

The following optometrists, educators and scientists were elected to Fellowship in the American Academy of Optometry during the first quarter of 1952. The Academy welcomes these new members.

Dr. M. J. Almstead, Savings Bank Building, Skaneateles, New York.

Dr. C. W. Bobier, R. O., College of Optometry, 140 St. George Street, Toronto, Ontario, Canada.

Mr. John K. Davis, American Optical Company, Research Laboratories, 689 Hope Street, Springdale, Connecticut.

Dr. Benjamin Gold, 76 Hanson Place, Brooklyn, New York.

Dr. George F. Jones, 511 East State Street, Salem, Ohio.

Mr. John Murray Rusk, 59 Newmarket Street, Ayr, Ayrshire, Scotland.

Dr. Raoul W. Sabatini, Chicago College of Optometry, 2315 North Clark Street, Chicago, Illinois.

Dr. J. C. Simpson, 213 North Jefferson Street, El Dorado, Arkansas.

Dr. Charles Reese Stewart, School of Optometry, The Ohio State University, Columbus, Ohio.

Dr. Roy Teshima, Northern Illinois College of Optometry, 4170 Drexel Boulevard, Chicago, Illinois.

ACADEMY LUNCHEON AT MIAMI BEACH

A luncheon for Academy members attending the Annual Congress of the American Optometric Association will be held at the National Hotel, Miami Beach, Florida at 12 Noon, Monday, June 9.

This luncheon is sponsored by the Florida Chapter of the American Academy of Optometry, and all members are urged to attend and bring guests if they choose. Dr. Walter C. Kennedy, President of the Florida Chapter, will preside at the luncheon and the informal get-together which will precede the affair.

Reservations for the luncheon will be made through the Florida Chapter at the registration desk at the A.O.A. Convention Headquarters.

LOCAL CHAPTER ACTIVITIES

NEW YORK ACADEMY OF OPTOMETRY

The New York Academy recently elected officers for 1952 as follows: President, Dr. Edward Steinberg; vice president, Dr. Joseph Carlson; treasurer, Dr. Willis Blee; secretary, Dr. Herman Sager. Recent activities of the chapter include a lecture presented by Dr. William Feinbloom entitled "Latest Developments in the Field of Contact Lenses," and attendance at an actual corneal transplantation at the Corneal Bank of Manhattan Eye and Ear Hospital, with an accompanying explanation by Dr. H. M. Katzin.

SOUTHERN CALIFORNIA CHAPTER

Fellows of the Southern California Chapter heard two outstanding speakers at the April meeting. Dr. Carl Trieb, professor of physical education at Stanford, discussed "Considerations to Physical Education." Fellow Harry L. Fuog's subject was "Optometric Values."

CURRENT COMMENTS

Virginia Huck
Editorial Assistant

Optometrists will confer a favor by sending news items of general interest for this department: such as relate to new instruments, clinical techniques, education, visual health and optometric legislation and organization.

A.O.A. CONGRESS SPEAKERS

Guest speakers at the coming A.O.A. Congress in Miami Beach, Florida include the following: Colonel R. L. Black, Chief of the Medical Service Corps, who is speaking on "Administrative Problems of the Medical Service Corps"; Dr. Stella S. Center, Reading Consultant, "How Visual Problems Affect Reading in School Children"; Sylvester Guth, Director of Lighting Research, General Electric Company, Nela Park, "Lighting and Achievement."

On Monday, June 9, 1952, a panel discussion, "Eyes or Vision," will be carried on by Dr. Darell Boyd Harmon, Austin, Texas; Dr. Frances Ilg, New Haven, Connecticut; Dr. Marguerite Thoma Eberl, Milwaukee, Wisconsin, and Dr. James D. MacConnell, Palo Alto, California.

Meeting concurrently with the A.O.A. Congress at special luncheons and dinners will be alumni of Southern College of Optometry,

Northern Illinois College of Optometry and Chicago College of Optometry as well as the American Academy of Optometry, Omega Epsilon Phi, Omega Delta, Beta Sigma Kappa, Mu Sigma Pi and Phi Theta Upsilon.

Registrations for the Congress are to be made through the Congress Committee office, 528 Lincoln Road, Miami Beach, Florida. Time—June 8-11, 1952.

CAMPUS NEWS

Ohio State University's School of Optometry has been granted separate school status within the College of Science, Literature and Arts, according to a recent announcement from President Howard L. Bevis. The School of Optometry has been operating as a unit of the department of physics and astronomy—its original status under the direction of Dr. Charles Sheard in 1914.

Pennsylvania State College of Optometry will hold its annual practitioners' clinical and educational week June 2-6, 1952. This Spring's program is aimed to provide an intensive, swift brush-up on external and internal examining procedures, interpretation and application of ophthalmometric findings, retinoscopic and subjective examinations, accommodation-convergence relationships and other vital subjects of interest to practicing optometrists.

Southern College of Optometry graduated 15 at its recent commencement. Dr. M. E. Broom, dean, presented the degrees, and Horace Hull, president of Hull-Dobbs and an outstanding Southern civic leader, gave the commencement address.

Dr. Henry Knoll, faculty member of the *Los Angeles College of Optometry* spoke on May 7 to the Southern California Chapter of the Illuminating Engineering Society on "Illumination and Sun Glasses."

Northern Illinois College of Optometry alumni gathered May 18 at the Hotel Roosevelt, New York City, to hear Dr. Richard Feinberg, N.I.C.O. Dean, outline recent innovations, improvements and aspirations for the College. The meeting was held in conjunction with the New York Optometric Association annual convention.

Pacific University College of Optometry will hold its Second Annual Clinical Workshop, June 22-26, at the school at Forest Grove. This seminar is being held in cooperation with the Educational Committee of the Oregon Optometric Association. The graduate short course will cover those subjects used by optometrists in making ocular examinations and refractions. Reservations should be sent to Dr. D. T. Gans at the college.

PLATO

Several years ago, this department reported that Dr. Eugene Freeman, Dean of Chicago College of Optometry, was working with David Appel, book editor of the *Philadelphia Inquirer*, on a series of books to be published under the title, "Library of Great Ideas." Book one is now off the press entitled "The Great Ideas of Plato." (Lantern Press, Inc., 257 Fourth Avenue, New York 10, New York, $3.00).

This first book, like the others to follow on Aristotle, Descartes, Locke, Schopenhauer, Hume, etc., is the cooperative effort of Dr. Freeman and Mr. Appel to interpret the great philosophers' works in understandable terms so that more people can enjoy and benefit from the thinking of these eminent men.

In "The Great Ideas of Plato," the authors have selected direct quotations from Plato and explained them in relation to everyday affairs.

Dr. Freeman is well known in optometric circles for his work in optometric education, ethics and in philosophy, and this book has been awaited by his colleagues and friends with great interest.

OPTOMETRY IN BRITTANICA

The coming edition of Encyclopedia Brittanica will carry a short essay on the profession of optometry, due to efforts of the Department of Public Relations of the American Optometric Association. The thousand word article to be included in Brittanica has been prepared by Dr. Elmer N. Soles, and emphasizes the "psychological aspects of vision [?] which distinguish optometric methods of examination and correction," according to the A.O.A. Previous editions of this encyclopedia have carried only a brief statement describing optometry as the "non-medical care of eyesight."

NEWS BRIEFS

Bay State Optical Company announces the appointment of Joseph J. Margules as vice president and secretary. He has been active in the optical industry in the United States since 1945; prior to this he was owner of a manufacturing plant in Tours, France for nearly 25 years. Bay State is currently featuring *Bay Belle*, a brow-line type of combination frame featuring a new pierced bridge. . . . It's time for sun-glasses again in the North, and American Optical Company is featuring a type for women which deserts the "goggle" type altogether—a new metal sun glass featuring wide peripheral vision afforded by a modernistic square lens shape. Soft-Lite Lens Company is currently breaking a Spring-Summer campaign on Soft-Lite 4D Sport Shade lenses and publishing brochures on the value of prescription ground sun glasses. . . . The

Better Vision Institute's president, M. J. Julian, recently toured England and Scotland as a guest of the British Optical Industry, speaking before manufacturers, opticians, editors and public relations people, telling of the structure, activities and achievements of B.V.I. . . . Dr. William Smith, Boston, Massachusetts optometrist was a recent guest speaker of the New England Section of the Optical Society of America. He spoke on "Eyes in Industry" at their Spring meeting. . . . Continental Optical Company's new modern plant at Indianapolis is now operating. This plant was constructed for the manufacture of Kurova and Conoptex lenses. . . . Three nationally prominent visual specialists spoke at the recent annual meeting of the Minnesota Optometric Association in Minneapolis in April. Dr. Robert E. Bannon, Bureau of Visual Science, American Optical Company, Southbridge, Massachusetts, made several appearances during the three-day session, speaking on aniseikonia, and refractive techniques. Dr. T. R. Fritsche, M.D., New Ulm, Minnesota, discussed the problem of "Cataracts—Refraction Problems and Referral for Medical Care." Dr. D. J. Chatham, Faribault, Minnesota, talked on "A Simple Method of Taking Visual Fields." . . . The Women's Auxiliary of the American Optometric Association is working hard on its campaign to have a green, postage-sized visual care A.O.A. sticker on every outgoing piece of mail from optometric offices. If you aren't participating, contact your State Association headquarters. . . . The National Board of Examiners in Optometry, under the direction of President Rudolph Ehrenberg, Granite Falls, will hold its first examinations in June of this year in all optometric colleges.

BOOK NOTICES

TEXTBOOK OF REFRACTION. Edwin Forbes Tait (Temple University, Philadelphia). W. B. Saunders Company, New York, 1951, 418 pp., 93 figs., $8.00.

This book was designed to fill "the need for a textbook of refraction and ocular neuromuscular abnormalities, organized for convenience in teaching both undergraduate and graduate students, and embodying the physiological background so necessary in those fields."

That there is a need for such a text is undeniable. Most teachers of refraction in our schools are clinicians who have not attempted to publish in a well organized manner the procedures they teach. Prior to becoming a physician and an ophthalmologist, Tait was a member of the faculty of the Pennsylvania College of Optometry for several

years. Hence, one may conclude that Tait is familiar with the optometric, as well as the ophthalmological, views on refraction and related subjects. The book is dedicated to Charles Sheard whom the author acknowledges as teacher and counselor.

The first nine chapters are devoted to discussions of the basic considerations necessary for the study of refractive and motility anomalies. Included is a chapter on ocular reflexes and accommodation stimulus—response mechanisms, as well as short chapters on hyperopia, myopia, astigmia, presbyopia, and aniseikonia. Chapters X and XI introduce the subjects of amblyopia, subnormal vision, reading difficulties, visual screening, illumination and photophobia.

Chapters XII through XIX are concerned with binocular coordination, anatomy and physiology of the extraocular muscles, binocular fusion, retinal correspondence, heterophoria and heterotropia, including methods of measuring and correcting these anomalies.

Methods of Refraction, Keratometry, Static and Dynamic Skiametry, Cycloplegics, Subjective Methods in Normal and Subnormal Vision constitute the subject matter of Chapters XX to XXV. These chapters contain practical information not only with respect to the optical principles involved and the methodologies found most useful, but also relative to the intelligent limitations and interpretations of the accumulated data.

ROBERT E. BANNON

ABSTRACTS

THE RELATIONSHIP OF HETEROPHORIA TO DEPTH PERCEPTION IN AVIATION. John V. V. Nicholls. Am. J. Ophth., 33 (12), 1891-1903, December, 1950.

This is the third in a series of papers reporting research by the Royal Canadian Air Force. The studies were executed with proper controls, statistical methods, follow-up data, and due consideration of the pertinent literature.

Some of the conclusions are of special interest to optometrists. It was found that aside from anoxia, there is little sound evidence that good muscle balance or stereopsis is essential to safe flying. Although there is some indication in the literature that orthoptic training may reduce the time for soloing in some individuals, the orthoptic studies by the Royal Canadian Air Force indicated the use of orthoptics is of little economic value except to salvage personnel.

Although so little was found in the relationship of ocular muscle balance to flying performance, several studies showed a definite relationship between visual acuity and flying performance. It appears that poor visual acuity has a definitely deleterious effect upon the ability to learn to fly. In a study of 1,448 pilot trainees, 69.5 per cent with 20/20 vision in the worse eye completed their training successfully, whereas only 44.5 per cent having 20/40 vision in the worse eye were successful.

On the basis of the findings presented in this report, the author recommends that no limitations be placed upon ocular muscle balance for pilot duty, provided the candidate has no frank diplopia.

ROBERT E. BANNON.

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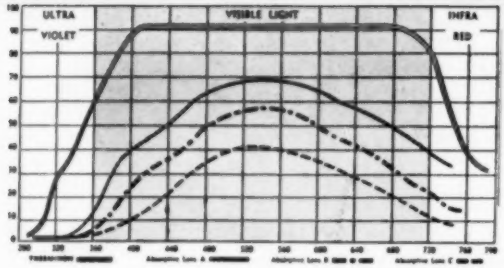

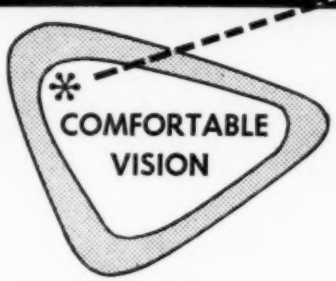

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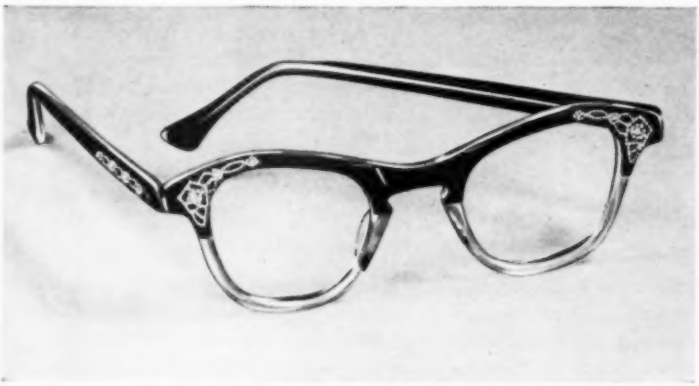

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